CHAPTER 12

PAVEMENT DRAINAGE SYSTEMS

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12.1 Overview

12.1.1 Introduction

Storm drainage facilities for pavement drainage consist of curbs, gutters, storm drains, channels and culverts. This chapter discusses the aspects of pavement drainage design such as system planning, pavement drainage, gutter flow calculations, and inlet sizing and location. The pipe sizing and hydraulic grade line calculations for the design of storm drains is covered in Chapter 13. Pump stations are discussed in Chapter 14. Structures that convey flows through the highway are discussed in Chapter 9 Culverts or Chapter 10 Bridges.

12.2 Design Goals

12.2.1 General

A storm drainage system for a street or highway is a collection of structures to collect and convey storm water runoff from land areas to a discharge location in a manner that adequately drains the roadway and minimizes the potential for flooding and erosion to adjacent properties.

The system begins with a concentration system such as gutters and channels, a system of inlets that pass the collected flows into a conveyance system of pipes or channels, that has structures to allow the connection or access to them. The collected flows are eventually conveyed to an outfall. The outfall may discharge to a pump station, storage facilities, or a larger conveyance, such as a storm drain channel. The cost of drainage facilities is neither incidental nor minor on most roads. The quality of the final system usually reflects the attention given to every aspect of the design. The design of a drainage system must address the needs of the traveling public as well as those impacted by the project.

The storm drain system may be categorized as a surface system and a subsurface system. The surface system usually involves gutter flow and inlet interception. This system is used to control the location and amount of water flowing along the gutters or ponding at sags to quantities that will minimize interference with the passage of traffic at the design storm event. This is accomplished by placing inlets at such points and at such intervals to intercept and capture flows as necessary to satisfy the spread and depth criteria for the specified storm frequency.

The subsurface system includes the pipes that convey the flow and the structures that connect the inlets to the pipes. There may be additional structures that allow access to the subsurface system while not being intended for capturing of flows into the subsurface system. The subsurface system allows for the entry of water at each inlet and conveys the collected flows to the discharge location in a manner that contains the flows for the design event. This is accomplished by sizing the pipes and evaluating the energy losses so that the hydraulic grade line is just near the top of the pipes for the design storm event.

Some of the constraints in meeting the hydraulic goals are the available r/w, utilities, budget, alignment, and regulations. The successful design meets the stated hydraulic goals at the lowest total economic costs: construction, maintenance, right-of-way and environmental.

12.3 Symbols and Definitions

12.3.1 Symbols

To provide consistency within this chapter as well as throughout this manual the symbols in Table 12-1 will be used. These symbols were selected because of their wide use in storm drainage publications.

Table 12-1 Symbols And Definitions

Symbol	Definition	Units
A	Area of cross section	ft^2
A	Watershed area	acres
a	Depth of depression	inches
C	Runoff coefficient or coefficient	-
d	Depth of gutter flow at the curb line	ft
D	Diameter of pipe	ft
E_o	Ratio of frontal flow to total gutter flow Q_w/Q	-
h	Height of curb opening inlet	ft
H	Head loss	ft
I	Rainfall intensity	in./hr
K	Coefficient	-
L	Length of curb opening inlet	ft.
L	Pipe length	ft.
L	Pavement width	ft.
L	Length of runoff travel	ft.
n	Roughness coefficient in Manning formula	-
P	Perimeter of grate opening, neglecting bars and side against curb	ft.
P	Tire pressure	psi
Q	Rate of discharge in gutter	ft^3/sec
Q_i	Intercepted flow	ft^3/sec
Q_s	Gutter capacity above the depressed section (See Figure 12-1)	ft^3/sec
Q_T	Total flow	ft^3/sec
Q_W	Gutter capacity in the depressed section (See Figure 12-1)	ft^3/sec
R_h	Hydraulic radius	ft
S or S_x	Pavement cross slope	ft/ft
S	Crown slope of pavement	ft/ft
S or S_L	Longitudinal slope of pavement	ft/ft
S_w	Depressed section slope (See Figure 12-1)	ft/ft
T	Top width of water surface (spread on pavement)	ft
t_c	Time of concentration	min
T_D	Tire tread depth	in.
T_s	Spread above depressed section	ft
TXD	Pavement texture depth	in.
V	Vehicle speed	mph
V	Velocity of flow	ft/sec
W	Width of depression for curb opening inlets	ft
W_d	Rotational velocity on dry surface	rpm
WD	Water depth	in.

12.3 Symbols and Definitions (continued)

Table 12-1 Symbols And Definitions (continued)

Symbol	Definition	Units
W_w	Rotational velocity on flooded surface	rpm
y	Depth of flow in approach gutter	ft
Z	T/d, reciprocal of the cross slope	-

12.3.2 Definitions

Following are discussions of terms that will be used throughout the remainder of this chapter in dealing with different aspects of storm drainage analysis.

Bypass/Flowby (Carry over) -- Occurs at an inlet on grade. It is the flow that is not captured at an inlet on grade, bypasses, and flows to the next inlet downgrade. Inlets on grade are usually designed to allow a certain amount of flowby. Inlets located upstream of an area where pedestrians are expected to use the street may be designed for zero flowby.

Capture Ratio-- The percent of length, area or perimeter expressed as a decimal (0.5, 0.67 or 0.8) of an inlet that is effective in capturing flow after accounting for obstruction by debris. See Chapter 600 of the RDG for appropriate values.

Crown--The crown is the top inside of a pipe, also referred to as the soffit.

Culvert--A culvert is a closed conduit whose purpose is to convey surface water under a roadway, railroad or other impediment. It may have inlets connected to it.

Curb-Opening Inlet--A drainage inlet consisting of a vertical opening in the roadway curb.

Downdrain – an inlet used to convey stormwater from the roadway down the embankment slope consisting of a gap in the roadway curb face that connects to a pipe in the sloped embankment.

Embankment Curb-- The curb along the edge of pavement in fill areas to contain and convey flow along the highway. It inhibits flow from flowing over the side of the embankment.

Energy Grade Line – The locus of points that the describe the total energy of the flowing water, it includes the elevation, pressure and velocity heads. See Hydraulic Grade Line.

Equivalent Cross Slope-- An imaginary straight cross slope having conveyance capacity equal to that of the given compound cross slope.

Flanking Inlets-- Inlets placed upstream and on either side of an inlet at the low point in a sag vertical curve. The purpose of these inlets is to intercept debris as the slope decreases and to act in relief of the inlet at the low point.

12.3 Symbols and Definitions (continued)

12.3.2 Definitions (continued)

Flow-- Flow refers to a quantity of water that is flowing.

Flow-by-- See Bypass

Flume-- An open structure with vertical or nearly vertical sides that carries water.

Frontal Flow-- The portion of the flow that passes over the upstream side of a grate.

Frontal Interception-- Flow that is intercepted by a grate along its upstream side. The interception may be less than the frontal flow

Grate Inlet-- A drainage inlet composed of a grate in the roadway section or at the roadside in a low point, swale or channel.

Grate Perimeter-- The sum of the lengths of all sides of a grate, except that any side adjacent to a curb is not considered a part of the perimeter in weir flow computations.

Gutter-- That portion of the roadway section adjacent to the curb that is utilized to convey stormwater runoff. A composite gutter section consists of the section immediately adjacent to the curb, usually 1.5 or 2.0 ft at a cross-slope of say 0.0588 ft/ft, and the parking lane, shoulder, or pavement at a cross slope of a lesser amount, say 0.02 ft/ft. A uniform gutter section has one constant cross-slope. See Section 12.5.4.3 for additional information.

Hydraulic Grade Line-- The hydraulic grade line is the locus of elevations to which the water would rise in successive piezometer tubes if the tubes were installed along a pipe run (pressure head plus elevation head). See also Energy Grade Line

Inlet – a structure designed to intercept and capture flow. The more common types are grate, curb-opening and slotted drain.

Inlet Efficiency-- The ratio of flow intercepted by an inlet to total flow in the gutter.

Invert-- The invert is the inside bottom of the pipe.

Lateral Line-- A that connects inlets to the main discharge line..

Pressure Head-- Pressure head is the height of a column of water that would exert a unit pressure equal to the pressure of the water.

Sag Point-- A low point in a vertical curve. Major Sag Point -- A major sag point refers to a low point that can overflow only if water can pond to a depth of 2.5 feet or more.

12.3 Symbols and Definitions (continued)

12.3.2 Definitions (continued)

Scupper--A hole or slot through the curb, barrier or a bridge deck for the purpose passing drainage. It has no pipe connected to it. A scupper may connect to a lined flume.

Side-Flow-- Flow that is flowing along the side of a grate inlet, as opposed to frontal flow.

Side-flow Interception-- Flow that is intercepted along the side of a grate inlet, the interception may be less than the side-flow.

Slotted Drain Inlet-- A drainage inlet composed of a continuous slot built into the top of a pipe which serves to intercept, collect and transport the flow.

Storm Drain-- A storm drain is defined as that portion of the storm drainage system that receives runoff from inlets and conveys the runoff to some point where it is then discharged into a channel, waterbody, or other piped system. A storm drain may be a closed-conduit, open-conduit, or some combination of the two. Design information is provided in Chapter 13 Storm Drains.

Spillway-- An inlet used to convey stormwater from the roadway down the slope consisting of a opening in the roadway curb face that connects to a flume in the sloped embankment. See scupper and flume.

Splash-Over-- Portion of frontal flow at a grate that skips or splashes over the grate and is not intercepted.

Spread-- The top width of stormwater flow in the gutter measured laterally from the roadway curb. See Section 12.7 for computation methodology. The allowable spread is specified in section 600 of the Roadway Design Guidelines.

Trunk Line-- A trunk line is the main storm drain line. Lateral lines may be connected at inlets, access structures, or with “wyes” or “tees”. A trunk line is sometimes referred to as a "main."

Velocity Head-- Velocity head is a quantity proportional to the kinetic energy of flowing water expressed as a height or head of water, ($V^2/2g$).

12.4 System Planning

12.4.1. Introduction

System planning must occur prior to detailed design of a storm drain system. The master-planning phase should identify the areas to be drained, possible locations of the conveyance system and discharge outfall. The preliminary design is consistent with the broad-system outlines established in the master-planning phase, but provides additional detail on locations of individual drainage structures and features. Activities entail a more detailed hydraulic analysis. It will explicitly account for how the proposed facility fits into the larger-scale plans. It includes topographic mapping on which sub-basins areas and proposed storm drainage facilities have been superimposed as well as locations of other features such as detention basins, pump stations and outfall. The final design will finalize design discharges and determine the dimensions of the inlets and other hydraulic structures. The final design activities and decisions will be documented.

Detention Storage

Reduction of peak flows can be achieved by the storage of runoff in detention basins, storm drainage pipes, swales and channels and other detention storage facilities. Stormwater can then be released to the down-stream conveyance facility at a reduced flow rate. The concept should be considered at locations where existing downstream conveyance facilities are inadequate to handle peak flow rates from highway storm drainage facilities. Additional benefits may include the reduction of cost by downstream pipe sizes and the improvement of water quality by removing sediment and/or pollutants. Design consideration and procedures are presented in Chapter 15 Storage Facilities.

12.4.2 General Design Approach

The design of any storm drainage system involves the accumulation of basic data, familiarity with the project site, and a basic understanding of the hydrologic and hydraulic principles and drainage policy associated with that design. The design of a storm drain system is generally a process that evolves as a project develops. The primary ingredients to this process are listed below in a general sequence by which they may be carried out.

1. Data collection (See Chapter 6 — Data Collection and 12.4.3)
2. Coordination with other agencies (12.4.4)
3. Initial System Design (12.4.5)
4. Inlet location and spacing (12.11 & 12.12)
5. Plan layout of storm drain system (Chapter 13.5)
    - locate main outfall
    - determine direction of flow
    - locate existing utilities
    - locate connecting mains
    - locate access holes
6. Size the pipes (Chapter 13.5)
7. Review hydraulic grade line (Chapter 13.6)
8. Prepare the plan
9. Provide documentation (Chapter 4)

12.4 System Planning (continued)

12.4.2.1 Data Collection

Although the primary use of storm drains on the state highway system is to drain the roadway pavement, the outfall of storm drain systems may interact with local drainage systems. If this is so, the designer must collect information regarding the local drainage system. The data needs may include land use patterns, the nature of the physical development of the area(s) to be served by the storm drainage system, the stormwater management plans for the area and the ultimate pattern of drainage (both overland and by storm drains) to the outfall location. Furthermore, there should be an understanding of the nature of the outfall since it usually has a significant influence on the storm drainage system. In environmentally sensitive areas, there may be water quality requirements to consider as well.

Actual surveys of these and other features are the most reliable means of gathering the required data. Existing topographic maps, available from the U. S. Geological Survey, the Soil Conservation Service, many municipalities, some county governments and even private developers are also valuable sources of the kind of data needed for a proper storm drainage design. Where the system outfall interacts with the local drainage system, local governmental agencies should be consulted regarding plans for the area in question. Often, in rapidly growing urban areas, the physical characteristics of an area to be served by a storm drainage system may change drastically in a very short time. In such cases, the designer is to anticipate these changes and consider them in the storm drainage design. Comprehensive Stormwater Management Plans and Floodplain Ordinances should be reviewed when they are available.

12.4.2.2 Cooperative Projects

Cooperative storm drain projects with local government agencies may be beneficial where both a mutual economic benefit and a demonstrated need exist. Early coordination with the local government agency involved is necessary to determine the scope of the project. If cooperative projects are to be undertaken, cost-sharing and design methodology must be documented in agreements.

12.4.2.3 Initial System Design

Preliminary sketches or schematics, featuring the basic components of the intended design, should be developed at the beginning of the design process. Such sketches should indicate watershed areas and land use, existing drainage patterns, plan and profile of the roadway, street and driveway layout with respect to the project roadway, underground utility locations and elevations, locations of proposed retaining walls, bridge abutments and piers, logical inlet and access hole locations, preliminary lateral and trunk line layouts and a clear definition of the outfall location and characteristics. This sketch of intended design elements should be reviewed for determination of areas that are incompatible with the project needs, including construction staging and utility conflicts. With this schematic, the designer is able to proceed with the detailed process of storm drainage design calculations, adjustments and refinements.

12.4 System Planning (continued)

12.4.2.3 Initial System Design (continued)

Layout Considerations

Consideration and planning should be directed toward avoidance of utilities and deep cuts. In some cases, traffic must be maintained or temporary bypasses constructed and temporary drainage provided for during the construction phase. Further consideration should be given to the actual trunk line layout and its constructibility. For example, will the proposed location of the storm drain interfere with in-place utilities or disrupt traffic? Some instances may dictate a trunk line on both sides of the roadway with very few laterals while other instances may call for a single trunk line. Such features are usually a function of economy but may be controlled by other physical features.

Storm drain pipes should not decrease in size in a downstream direction regardless of the available pipe gradient. Except in unusual circumstances, storm drains should discharge to a single outfall. A storm drain that branches, thereby distributing the discharge, should be avoided. Attention shall be given to the storm drain outfalls to insure that the potential for erosion is minimized.

12.5 Design Considerations

12.5.1 Introduction

The desired behavior for the roadway pavement drainage system is usually described in terms of Spread. Spread is the amount the flooded top width of the flow along the gutter. The allowable spread is specified in Chapter 600 of the Roadway Design Guide (RDG) in conjunction with a design flood frequency. The spread at the specified storm frequency is based on allowing operation of the highway without unduly burdensome cost. The major consideration for selection of a design spread is the highway classification as described by the roadway cross-section. The roadway cross-section influences the public expectations for finding water on the pavement surface. Other considerations include inconvenience, hazards and nuisances to pedestrian traffic and buildings adjacent to roadways that are located within the splash zone.

12.5.2 Hydrology

The Rational Method is the usual method to determine the peak flow rate for the design of storm drain systems. The rational method is described in the ADOT Hydrology Manual. Its use should be limited to systems with drainage areas of 160 acres or less. A minimum time of concentration of 10 minutes is generally acceptable. Drainage systems involving detention storage, pumping stations and large or complex storm systems will require the development of a runoff hydrograph. This may require the use of the HEC-1 procedures.

12.5 Design Considerations (continued)

12.5.3 Roadway Design Elements for Pavement Drainage

Roadway features that impact the handling of stormwater include:

- pavement width
- longitudinal and cross slope
- curb and gutter sections.

The pavement width, cross section shape and slope determine the time it takes for storm water to drain to the gutter section. The gutter cross-section and longitudinal slope control the quantity of flow that can be carried in the gutter section.

12.5.3.1 Longitudinal Slope

A minimum longitudinal gradient is more important for a curbed pavement than for an uncurbed pavement since it is susceptible to the spread of stormwater against the curb. Desirable gutter grades should not be less than 0.3% for curbed pavements with a minimum of 0.2%. Minimum grades can be achieved in very flat terrain by use of a rolling profile.

To provide adequate drainage in sag vertical curves, a minimum slope of 0.3% should be maintained within 50 feet of the level point in the curve. This is accomplished where the length of the curve divided by the algebraic difference in grades is equal to or less than 150; $K = L/A$, $(L_c/(g_1-g_2))$. Although ponding is not usually a problem at crest vertical curves, on extremely flat curves a similar minimum gradient should be provided to facilitate drainage.

12.5.3.2 Cross Slope

The design of pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. The USDOT, FHWA (FHWA-RD-79-30, 31, 1979) reports that cross slopes of 2% have little effect on driver effort in steering, especially with power steering, or on friction demand for vehicle stability.

12.5.3.3 Shoulder Gutter And/Or Curbs

Curbs are used where there is a need to control runoff from the pavement. This may be due to locations where concentration of runoff would erode fill slopes or would flow off the right-of-way at unwanted locations. Curbing may also serve other purposes that include traffic control, providing pavement delineation, containing the surface runoff within the roadway and away from adjacent properties, preventing erosion and enabling the orderly development of property adjacent to the roadway.

Curbs may be either mountable or barrier type. Mountable curbs are less than 6 inches in height and have rounded or plane sloping faces. If mountable curb is used, the gutter and shoulder grades should be the same to maximize the amount of flow than can be carried along the curb. Where barrier curbs are used, a steeper gutter cross slope can be effective at increasing gutter capacity and reducing spread on the pavement.

12.5 Design Considerations (continued)

12.5.3.3 Shoulder Gutter And/Or Curbs (continued)

A curb and gutter forms a triangular channel that can be an efficient hydraulic conveyance facility that can convey runoff of a lesser magnitude than the design flow without interruption of the traffic. When a design storm flow occurs, there is a spread or widening of the conveyed water surface and the water spreads to include not only the gutter width, but also parking lanes or shoulders, and portions of the traveled surface. This is the width the hydraulic engineer is most concerned about in curb and gutter flow, and limiting this width becomes a very important design criterion.

Shoulders should generally be sloped to drain away from the pavement, except with raised, narrow medians. Shoulder gutter and/or curbs may be appropriate to protect fill slopes from erosion caused by water from the roadway pavement. Shoulder gutter and/or curbs may be appropriate at bridge ends where concentrated flow from the bridge deck would otherwise run down the fill slope. This section of gutter should be long enough to include the transitions; it is usually located behind the guardrail at the end of the bridge. Shoulder gutters are not required on the high side of super-elevated sections or adjacent to barrier walls on high fills.

12.5.4 Roadside And Median Ditches

Roadside channels are commonly used with uncurbed roadway sections to convey runoff from the highway pavement and from areas that drain toward the highway. Due to right-of-way limitations, roadside channels cannot be used on most urban arterials. They can be used in cut sections, depressed sections and other locations where sufficient right-of-way is available and driveways or intersections are infrequent. Where practicable, the flow from major areas draining toward curbed highway pavements should be intercepted in the ditch as appropriate.

It is preferable to slope median areas and inside shoulders to a center swale, to prevent drainage from the median area from running across the pavement. This is particularly important for high-speed facilities and for facilities with more than two lanes of traffic in each direction.

12.5.5 Median/Median Barriers

Medians are commonly used to separate opposing lanes of traffic on divided highways. It is preferable to slope median areas and inside shoulders to a center depression to prevent drainage from the median area from running across the traveled pavement. Where median barriers are used and, particularly on horizontal curves with associated super-elevations, it is necessary to provide inlets and connecting storm drains to collect the water that accumulates against the barrier. Slotted drains adjacent to the median barrier and in some cases weep holes in the barrier can also be used for this purpose.

12.5 Design Considerations (continued)

12.5.6 Impact Attenuators

The location of impact attenuator systems should be reviewed to determine the need for drainage structures in these areas. Impact attenuators t usually require a clear or unobstructed opening as traffic approaches the point of impact to allow a vehicle to impact the system head on. If the impact attenuator is placed in an area where superelevation or other grade separation occurs, grate inlets and/or slotted drains may need to be placed to prevent water from running through the clear opening and crossing the highway lanes or ramp lanes. Curb, curb-type structures or swales cannot be used to direct water across this clear opening as vehicle vaulting could occur when the impact attenuator system is utilized.

12.5.7 Bridge Decks

Drainage of bridge decks is similar to other curbed roadway sections. It is often less efficient, because cross slopes are flatter, parapets collect large amounts of debris and small drainage inlets or scuppers have a higher potential for clogging by debris. Bridge deck construction usually requires a constant cross slope. The gutter spread should be checked to insure compliance with the design criteria in Section 12.9. Zero gradients and sag vertical curves and superelevation transitions with flat pavement sections should be avoided on bridges. The minimum desirable longitudinal slope for bridge deck drainage should be 0.5%.

Because of the difficulties in providing and maintaining adequate deck drainage systems, gutter flow from roadways should be intercepted before it reaches a bridge. In many cases, deck drainage must be carried several spans to the bridge end for disposal.

Many bridges will not require any drainage structures at all. The Rational equation and the spread equation can be combined to determine the length of deck possible without drainage structures and without exceeding the allowable spread. In many situations, scuppers are the recommended method of deck drainage because they can reduce the problems of transporting a relatively large concentration of runoff in an area of generally limited right-of-way. They also have a low initial cost and are relatively easy to maintain. However, the use of scuppers should be evaluated for site-specific concerns. Scuppers should not be located over embankments, slope pavement, slope protection, driving lanes, or railroad tracks. Runoff collected and transported to the end of the bridge should generally be collected by inlets and down drains, although flumes may be used for extremely minor flows in some areas.

Bridge Deck Drainage

For decks with a uniform cross slope the following equation can be utilized (FHWA Report No. RD-79-31, 1979):

$$L = \frac{0.56\,(S_x^{1.67})(S^{0.5})(T^{2.67})}{nCiW} \qquad \textbf{(12.1)}$$

Where: L = length of deck, ft
S_x = cross slope, ft/ft
S = longitudinal slope, ft/ft
T = allowable spread, ft
n = Manning's n, usually 0.016
C = runoff coefficient, usually 0.95
i = rainfall intensity, in./hr
W = width of drained deck, ft

12.5 Design Considerations (continued)

12.5.8 Gutter Flow

Once concentrated by curbs, the spread of the flow along the gutter must be evaluated for compliance with the design criteria. When the spread exceeds the allowable width, the flow is discharged by use of inlets or flumes. Gutter flow calculations are necessary to relate the quantity of flow to the spread of water on the pavement section. Composite gutter sections have a greater hydraulic capacity for normal cross slopes than uniform gutter sections and are therefore preferred. Refer to Section 12.7 for additional information and procedures.

12.5.9 Inlets

The term "inlets" refers to all types of inlets such as grate inlets, curb inlets and slotted inlets. Drainage inlets are sized and located to limit the spread of water on traffic lanes to tolerable widths for the design storm in accordance with the design criteria specified in Chapter 600 of the Roadway Design Guidelines, RDG. The width of water spread on the pavement at sags should not be substantially greater than the width of spread encountered on continuous grades. Grate inlets and depression of curb opening inlets should be located outside the through traffic lanes to minimize the shifting of vehicles attempting to avoid them. All grate inlets shall be bicycle safe when used on roadways that allow bicycle travel. Curb inlets are preferred to grate inlets at major sag locations because of their debris handling capabilities.

In sag vertical curves locations where significant ponding may occur such as at underpasses or in depressed sections, it is recommended practice to place flanking inlets on each side of the inlet at the low point in the sag. Review Section 12.10.3 for a discussion on the location of inlets.

12.6 Hydrology

12.6.1 Introduction

The rational method is the most common method in use for the design of storm drains when the momentary peak flow rate is desired. Its use should be limited to systems with drainage areas of 160 acres or less. Drainage systems involving detention storage and pumping stations require the development of a runoff hydrograph. Hydrology methods are described in the ADOT Hydrology Manual.

12.6.2 Rational Method

The Rational Equation is written as follows:

(12.2)

Where: Q = discharge, ft^3/sec
C = runoff coefficient
i = rainfall intensity, in/hr
A = drainage area, acres

12.6.2.1 Runoff Coefficient, C

The runoff coefficients for various types of surfaces are discussed in the ADOT Hydrology manual. The weighted C value is to be based on a ratio of the drainage areas associated with each C value as follows:

$$\text{weighted } C = [A_1C_1 + A_2C_2 + A_3C_3] / [A_1 + A_2 + A_3] \qquad \textbf{(12.3)}$$

12.6.2.2 Rainfall Intensity, i

Rainfall intensity (i): Rainfall intensity is the intensity of rainfall in inches per hour for a duration equal to the time of concentration. Intensity is the rate of rainfall per hour for the total amount of rainfall over an interval of time such that intensity multiplied by duration equals amount of rain, i.e., an intensity of 6 inches/hr for a duration of 10 min indicates a total rainfall amount of $6 \times 10/60 = 1.0$ in. The user will need Intensity-Duration information for computation of discharge for areas that have a time of concentration greater than the minimum. See ADOT Hydrology manual for data to be used for determining the intensity of rainfall.

12.6.2.3 Time Of Concentration, t_c

The time of concentration is defined as the period required for water to travel from the most hydraulically distant point of the watershed to the point of the storm drain system under consideration. The designer is usually concerned about two different times of concentration: one for inlet spacing and the other for pipe sizing. As one progresses downstream in a storm drain system there will be a major difference between the two times. The inlet time will be a function of the overland flow path to the inlet and not be altered by the subsurface flow paths. The pipe sizing time of concentration is the sum of time increments upstream of that pipe.

12.6 Hydrology (continued)

12.6.2 Rational Method (continued)

Inlet Spacing

The time of concentration (t_c) for inlet spacing is the time for water to flow from the hydraulically most distant point of the drainage area to the inlet, which is known as the inlet time. Usually this is the sum of the time required for water to move across the pavement or overland to the gutter, plus the time required for flow to move through the length of gutter to the inlet. For pavement drainage, when the total time of concentration is less than 10 minutes, a minimum t_c of 10 minutes should be used to estimate the intensity of rainfall. The time of concentration for the second downstream inlet and each succeeding inlet should be determined independently, the same as the first inlet. In the case of a constant roadway grade and relatively uniform contributing drainage area, the resultant time of concentration for each succeeding inlet could also be constant.

Overland time of concentration is developed by one of two methods: the SCS curve number or the kinematic wave approach. Channel time of concentration can be developed using one of three methods: SCS grassy waterway channel, Manning's equation, or the HEC-22 triangular gutter approach.

12.6.3 Detention

Estimation of the effects of detention requires a reservoir routing procedure such as that presented in Chapter 15 Storage Facilities. The use of reservoir routing procedures for peak flow attenuation is valid and particularly useful in a pump station based storm drainage system in which there are substantial lengths of large diameter pipes. In such systems, the storage capacity of the pipes can have a substantial effect on the final shape of the runoff hydrograph.

12.7 Gutter Flow Calculations

12.7.1 Introduction

Gutter flow calculations are necessary in order to relate the quantity of flow (Q) in the curbed channel to the spread of water on the pavement section. The nomographs in Figure 12-1 and Figure 12-2 can be utilized to solve for flow in uniform cross slope gutters, composite gutter sections and V-shape gutter sections. Figure 12-3 is also very useful in solving composite gutter section problems. Computer programs exist for this computation as well as inlet capacity. Where vertical curb is used, composite gutter sections have a greater hydraulic capacity for normal cross slopes than uniform gutter sections and are therefore preferred. Example problems for each gutter section are shown in the following sections.

The following form of Manning's equation is used for flow in a triangular section

$$\mathbf{Q = (0.56/n)\,(S_x^{1.67})(S^{0.5})(T^{2.67})} \qquad \mathbf{(12.4)}$$

Where: S_x = cross slope, ft/ft
S = longitudinal slope, ft/ft
T = spread, ft
n = Manning's n

12.7.2 Manning's n For Pavements

Type of Gutter or Pavement	Manning's n
Concrete gutter, troweled finish	0.012
Asphalt Pavement:	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter-asphalt pavement	
Smooth	0.013
Rough	0.015
Concrete pavement	
Float finish	0.014
Broom finish	0.016
For gutters with small slope, where sediment may accumulate, increase above n values by:	0.002
Reference: USDOT, FHWA, HDS-3 (1961)	

Normally use 0.016 for ADOT pavements.

12.7 Gutter Flow Calculations (continued)

12.7.3 Uniform Cross Slope Procedure

The gutter capacity of uniform cross slope section can be solved using the following procedure with the nomograph in Figure 12-1 or by equation 12.4:

CONDITION 1: **Given gutter flow (Q), find spread (T).**
Step 1: Determine input parameters, including longitudinal slope (S), cross slope (S_x), gutter flow (Q) and Manning's n.

Step 2: Draw a line between the S and S_x scales and note where it intersects the turning line.

Step 3: Draw a line between the intersection point from Step 2 and the appropriate gutter flow value on the capacity scale. If Manning's n is 0.016, use Q from Step 1; if not, use the product of Q and n.

Step 4: Read the value of the spread (T) at the intersection of the line from Step 3 and the spread scale.

CONDITION 2: **Given spread (T), find gutter flow (Q).**

Step 1: Determine input parameters, including longitudinal slope (S), cross slope (S_x), spread (T) and Manning's n.

Step 2: Draw a line between the S and S_x scales and note where it intersects the turning line.

Step 3: Draw a line between the intersection point from Step 2 and the appropriate value on the T scale. Read the value of Q or Qn from the intersection of that line on the capacity scale.

Step 4: For Manning's n values of 0.016, the gutter capacity (Q) from Step 3 is selected. For other Manning's n values, the gutter capacity times n (Qn) is selected from Step 3 and divided by the appropriate n value to give the gutter capacity.

12.7.4 Composite Cross Slope Procedure

The flow in a composite gutter section is determined by using Figure 12-2 and Figure 12-1. Figure 12-2 is used to find the flow in a gutter section of width (W) less than the total spread (T). Such calculations are generally used for evaluating frontal flow for grate inlets.

CONDITION 1: **Given flow (Q), find spread (T).**

Example: S = 0.01; S_x = 0.02; S_w = 0.06; W = 2.0 ft; n = 0.016; Q = 2.0 ft^3/sec; try Q_s = 0.7 ft^3/sec

Step 1: Determine input parameters, including longitudinal slope (S), cross slope (S_x), depressed section slope (S_w), depressed section width (W), Manning's n, gutter flow (Q) and a trial value of the gutter capacity above the depressed section (Q_s).

12.7 Gutter Flow Calculations (continued)

12.7.4 Composite Cross Slope Procedure (continued)

Step 2: Calculate the gutter flow in width, W (Q_w), using the equation:

$$\mathbf{Q_w = Q - Q_s} \tag{12.5}$$

$Q_w = 2.0 – 0.7 = 1.3\ ft^3/s$

Step 3: Calculate the ratios Q_w/Q and S_w/S_x and use Figure 12-2 to find an appropriate value of W/T. ($Q_w/Q = 1.3/2.0 = 0.65$ $S_w/S_x = 0.06/0.02 = 3$ From Figure 12-2, W/T = 0.27)

Step 4: Calculate the spread (T) by dividing the depressed section width (W) by the value of W/T from Step 3. T = 2.0/0.27 = 7.4 ft.

Step 5: Find the spread above the depressed section (T_s) by subtracting W from the value of T obtained in step 3. $T_s = 7.4 – 2.0 = 5.4$ ft.

Step 6: Use the value of T_s from Step 4 along with Manning's n, S and S_x to find the actual value of Q_s from Figure 12-1. From Figure 12-1 $Q_s = 0.49\ ft^3$/sec.

Step 7: Compare the value of Q_s from Step 5 to the trial value from Step 1. If values are not comparable, select a new value of Q_s and return to Step 1.

Compare 0.49 to 0.70 "no good," Try $Q_s = 0.80$; then Q_W =2.0-0.8 = 1.2; and Q_W/Q=1.2/2.0 = 0.6; From Figure 12-2, W/T = 0.23, then T = 2.0/0.23 = 8.7 ft. and $T_s = 8.7 – 2.0 = 6.7$ ft. From Fig 12-1, $Q_s = 0.81\ ft^3/s$ OK

ANSWER: Spread T = 8.6 ft

CONDITION 2: **Given spread (T), find gutter flow (Q).**

EXAMPLE: Spread T = 10.0 ft; W = 2.0 ft; T_s = 10.0-2.0 = 8.0 ft; S_x= 0.04;
S = 0.005 ft/ft; S_w = 0.06; n = 0.016; d = 5 inches

Step 1: Determine input parameters, including spread (T), spread above the depressed section (T_s), cross slope (S_x), longitudinal slope (S), depressed section slope (S_w), depressed section width (W), Manning's n and depth of gutter flow (d).

Step 2: Use Figure 12-1 to determine the capacity of the gutter section above the depressed section (Q_s). Use the procedure for uniform cross slopes- Condition 2, substituting T_s for T. From Figure 12-1, Q_s=3.0 ft^3/s

12.7 Gutter Flow Calculations (continued)

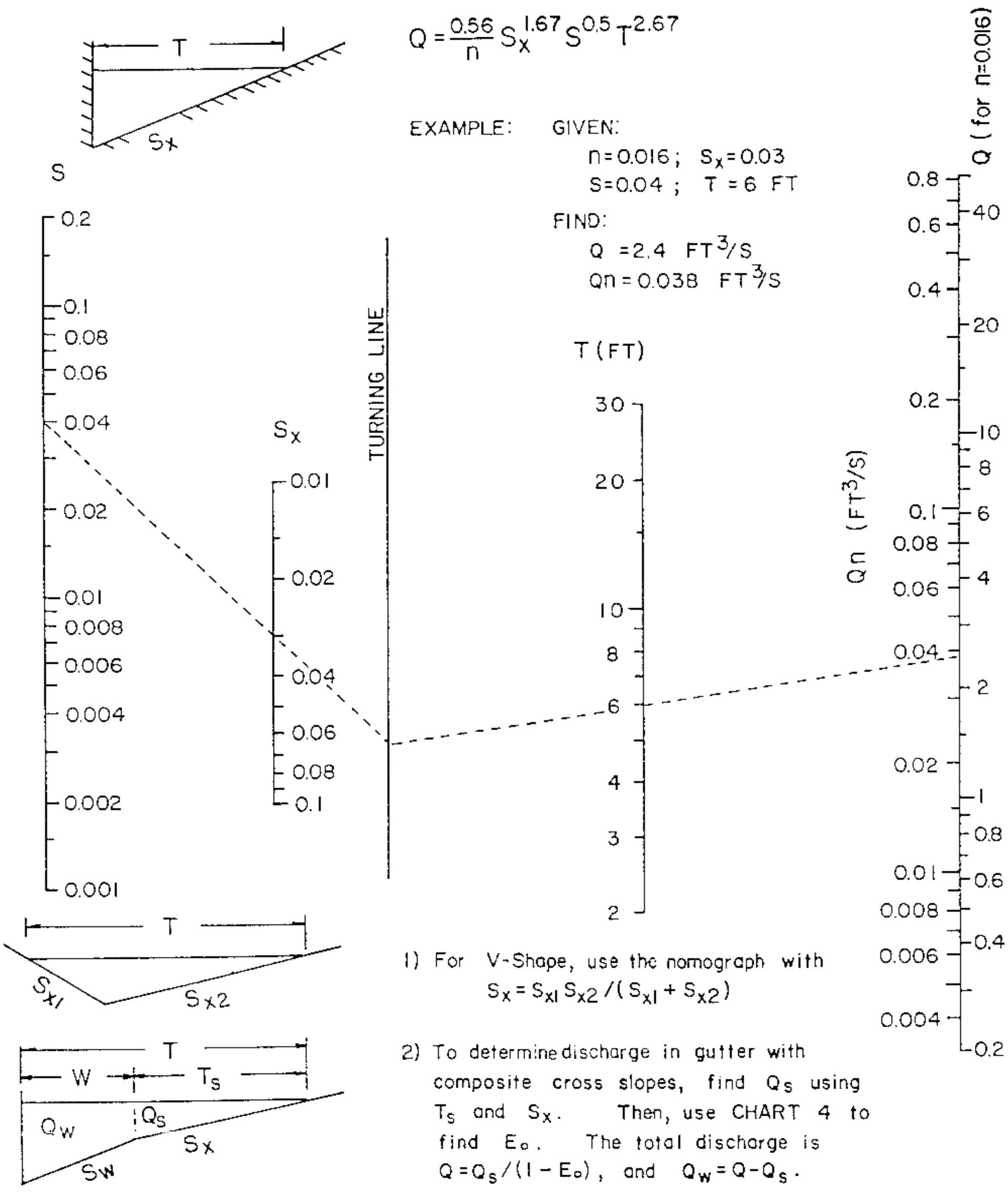


Figure 12-1 Flow In Triangular Gutter Sections

Source HEC-12

12.7 Gutter Flow Calculations (continued)

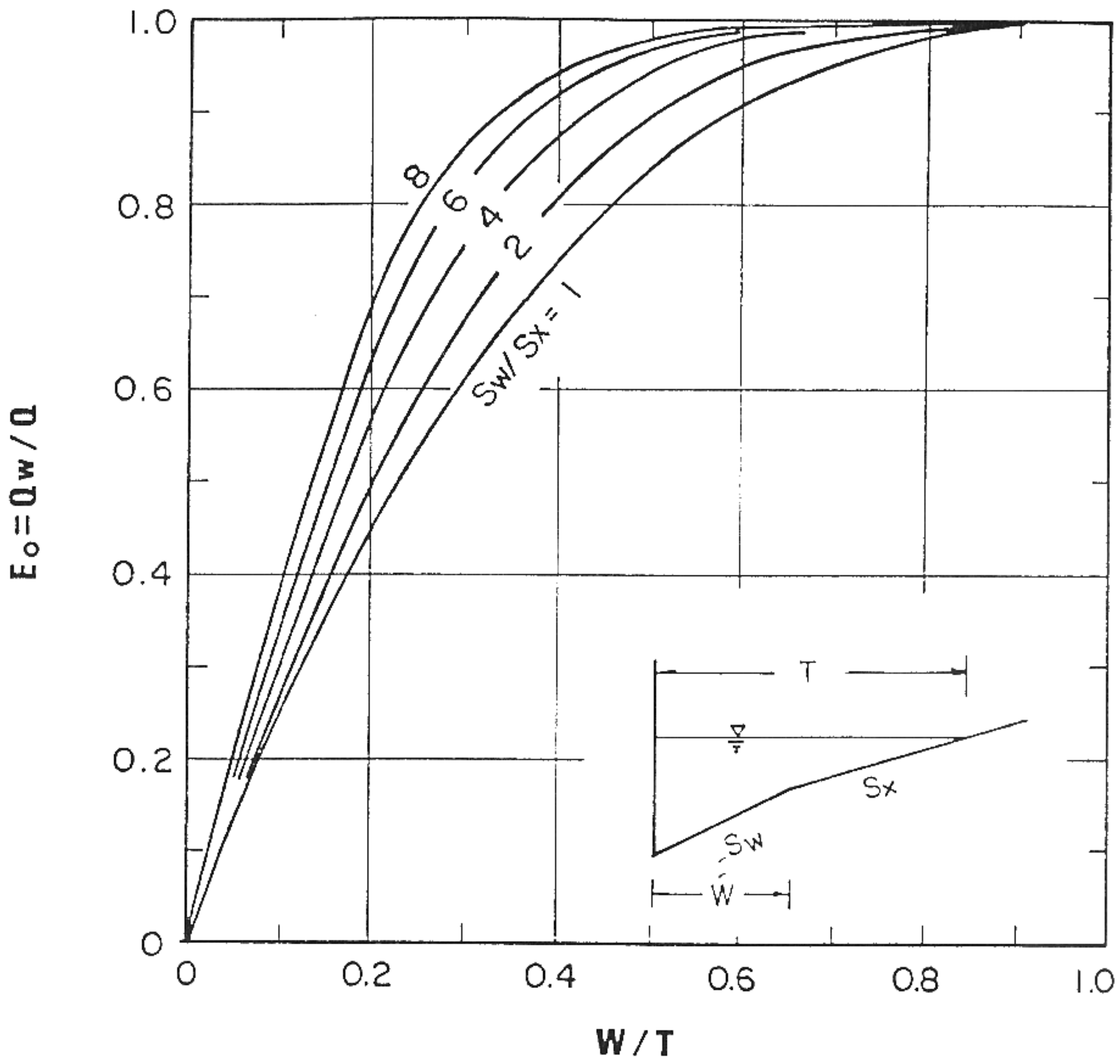


Figure 12-2 Ratio Of Frontal Flow To Total Gutter Flow

Source: HEC-12

12.7 Gutter Flow Calculations (continued)

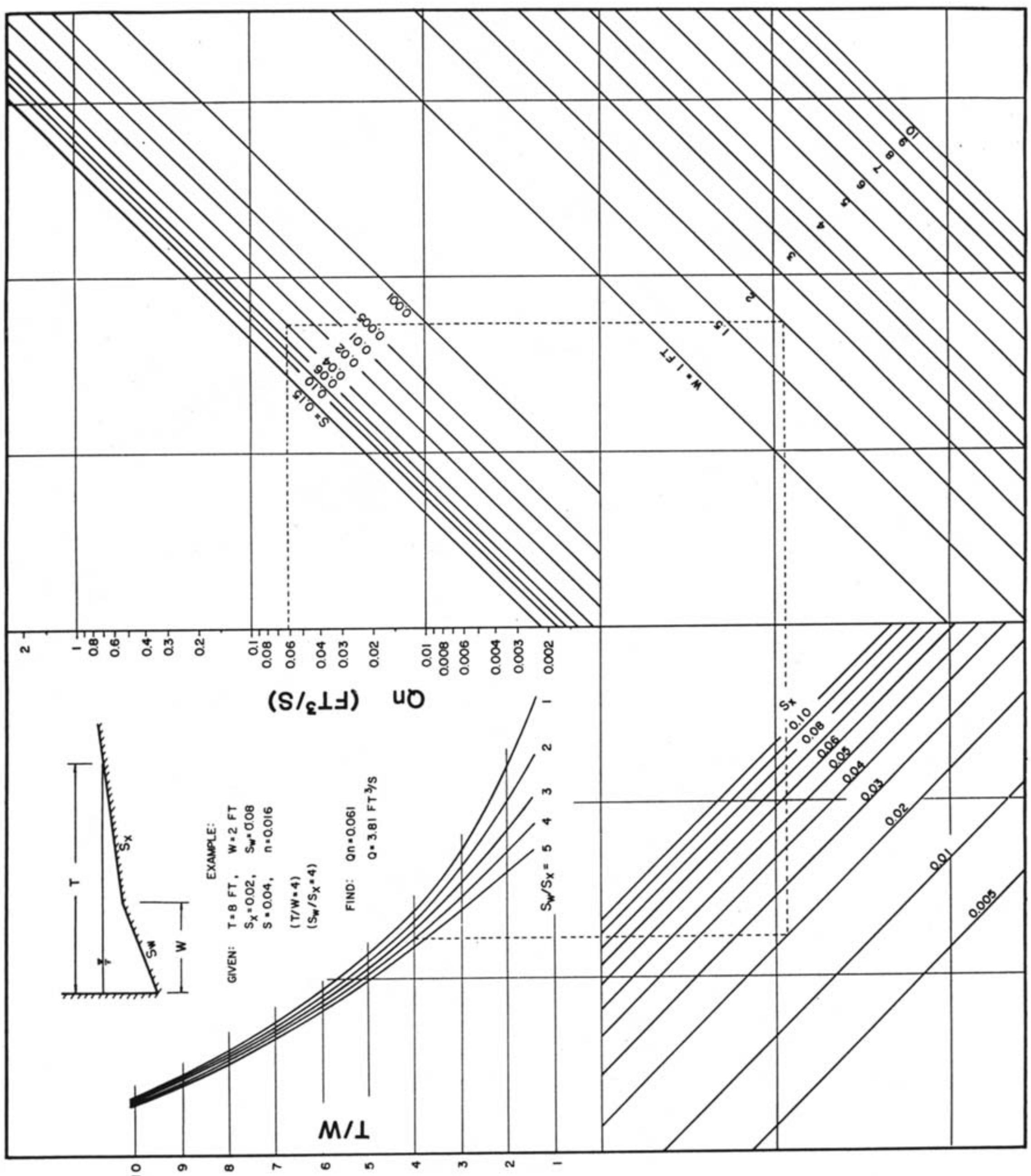


Figure 12-3 Flow In Composite Gutter Sections

Source: HEC 12

12.7 Gutter Flow Calculations (continued)

CONDITION 2: **Given spread (T), find gutter flow (Q)**. (continued)

Step 3: Calculate the ratios W/T and S_w/S_x, and from Figure 11-2, find the appropriate value of E_o, the ratio of Q_w/Q. W/T = 2.0/10.0 = 0.2; S_w/S_x = 0.06/0.04 = 1.5; From Figure 12-1 E_o = 0.46.

Step 4: Calculate the total gutter flow using the equation:

$$\mathbf{Q = Q_s/(1 - E_o)} \qquad \textbf{(12.6)}$$

Where: Q = gutter flow rate, ft^3/sec
Q_s = flow capacity of the gutter section above the depressed section, ft^3/sec
E_o = ratio of frontal flow to total gutter flow, Q_w/Q

Q = 3.0 / (1-0.46) = 5.55 ft^3/sec

Step 5: Calculate the gutter flow in width, W, using equation 12.5.

$Q_w = Q - Q_s$ = 5.55 – 3.0 = 2.25 ft^3/sec

NOTE: Figure 12-3 can also be used to calculate the flow in a composite gutter section.

12.7.5 V-Type Gutter Sections Procedures

Figure 12-1 can also be used to solve V Type channel problems. The spread, T, can be calculated for a given flow, Q, or the flow can be calculated for a given spread. This method can be used to calculate approximate flow conditions in the triangular channel adjacent to concrete median barriers. It assumes the flow is confined to the V channel with spread T_1.

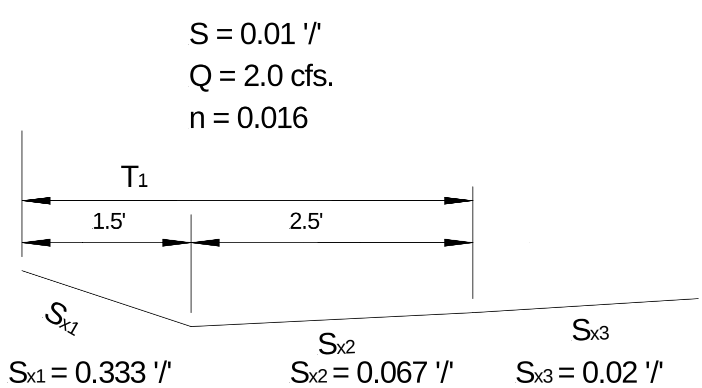


Figure 12-4 V Type Gutter

12.7 Gutter Flow Calculations (continued)

CONDITION 1: Given flow (Q), find spread (T).
Example: S = 0.01, S_{x1} = 0.33, S_{x2} = 0.066, S_{x3} = 0.020, n = 0.016, Q = 2.0 ft^3/s, shoulder = 4.0 ft.

Step 1: Determine input parameters, including longitudinal slope, S, cross slope $S_x = S_{x1}S_{x2}/(S_{x1}+S_{x2})$, Manning's n, total flow (Q).

Step 2: Calculate S_x
$S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2})$ $S_x = (0.33)(0.066)/(0.33 + 0.066) = 0.0555$

Step 3: Solve for T_1 using the nomograph on Figure 12-1.

T_1 is a hypothetical width that is correct if it is contained within S_{x1} and S_{x2}. From nomograph T_1 = 5.0 feet, however since the shoulder width of 4.0 ft is less than 5.0 ft, S_{x2} is 0.0666 and the pavement cross slope S_{x3} is 0.02, T will actually be greater than 5.0 ft; 5.0 – 1.5 = 3.5 ft which is > 2.5 ft., therefore the spread is greater than 5.0 ft.

Step 4: To find the actual spread, solve for depth at points B and C.
Point B: 3.5.0 ft @ 0.0666= 0.233 ft Point C: 0.233 - (2.5 @ 0.0666) = 0.066 ft

Step 5: Solve for the spread on the pavement. Pavement cross slope = 0.02.
$T_{0.015} = 0.066/0.02 = 3.325$ ft

Step 6: Find the actual total spread, T. T = 4.0 + 3.33 = 7.33 ft

CONDITION 2: Find Flow within Gutter.
Given depth (d), Find Flow (Q)
Example: n = 0.016, S = 0.01, S_{x1} = 0.33, S_{x2} = 0.066, d= 0.166 ft

Step 1: Determine input parameters such as longitudinal slope (S), Cross slope ($S_{x)}$ = $S_{x1}S_{x2}/(S_{x1} + S_{x2})$, Manning's n and allowable spread.

Step 2: Calculate S_x
$S_x = S_{x1}S_{x2}/(S_{x1} + S_{x2}) = (0.33)(0.066)/(0.33 + 0.066) = 0.0555$

Step 3: Calculate T
$T= d/(S_{x1})+d/(S_{x2}) = 0.166 /(0.333)+0.166/(0.066) = 0.500+ = 3.00$

Step 4: Using Figure 12-1, Solve for Q
For T = 3.0 ft, Q = 0.54 ft^3/sec
The equation shown on Figure 12-1 can also be used.
$Q= (0.56/0.016)*(0.0555)^{1.67}*(0.01)^{0.5}*(3.0)^{2.67} = 0.53\ ft^3/sec$

12.8 Inlets

12.8.1 General

Inlets are drainage structures utilized to collect surface water through grate, curb openings, or slotted drain and convey it to storm drains or directly outletting to culverts. This section will discuss the various types of inlets in use and recommend guidelines on the use of each type.

12.8.2 Types

Various types of inlets are in use; grates, curb openings and slotted drain. Curb opening inlets and slotted drain inlets are also used in combination with grate inlets. The gutter grade and cross slope and cross slope affect the portion of flow captured be each element. Grate inlets used at the downstream end of curb opening and slotted drain inlets provide access and increase the interception capacity for a given length of opening or slot. Combination inlets are desirable in sags because they can provide relief capacity in the event of plugging of the grate inlet.

12.8.2.1 Grate Inlets

These inlets consist of an opening in the gutter covered by one or more grates. On continuous grades they are most efficient in capturing frontal flow. In sag locations, they are more susceptible to clogging with debris, the use of standard grate inlets at sag points should be limited to minor sag point locations without debris potential. Special design (oversize) grate inlets or grate with curb opening can be utilized at major sag points if sufficient capacity is provided for clogging. In this case, flanking inlets are definitely recommended. **Grates shall be bicycle safe unless bike traffic is specifically excluded and structurally designed to handle the appropriate loads when subject to traffic.** See Sections 12.11.2 and 12.11.3 for capacity calculation methods.

12.8.2.2 Curb-Opening Inlets

These inlets are vertical openings in the curb. They are best suited for use at sag points since they can convey large quantities of water and debris. They are a viable alternative to grates in many locations where grates would be hazardous for pedestrians or bicyclists. They are not very efficient on steep continuous grades. **They shall not be used with pump station collection systems.** See Sections 12.11.4 and 12.11.5 for capacity calculation methods.

12.8.2.3 Slotted Drain Inlets

These inlets consist of a vertical slot opening in the gutter with bars perpendicular to the slot opening. For shallow flow slotted inlets function as weirs with flow entering from the side. They are used to intercept sheet flow and collect gutter flow with or without curbs. Grate inlets are used at the downstream end of slotted drain inlets to provide access and reduce the overall length of slotted drain. **Slotted drain inlets shall not be used for offsite collection nor where snow and ice are anticipated (above elevation 4000 ft. +/-).** See Sections 12.11.6 and 12.11.7 for capacity calculation methods.

12.8 Inlets (continued)

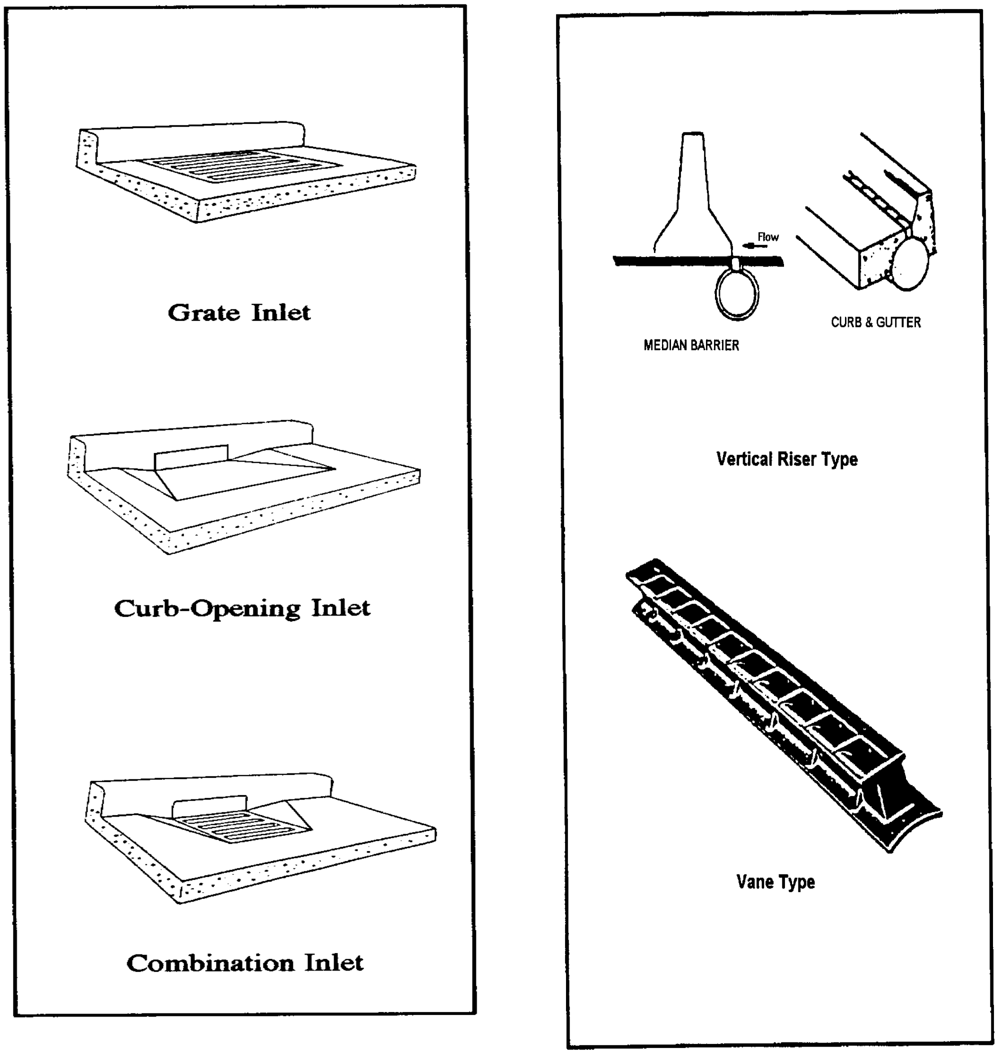


Figure 12-4 Inlets

12.8 Inlets (continued)

12.8.3 Inlet Locations

Inlets are required at locations needed to collect runoff within the design controls specified in the design criteria. In addition, there are a number of locations where inlets may be necessary with little regard to contributing drainage area. These locations should be marked on the plans prior to any computations regarding discharge, water spread, inlet capacity, or bypass-flow. Examples of such locations are as follows:

- Sag points in the gutter grade.
- Flanking inlets at sag points (see section 12.9.8)
- Upstream of median breaks, entrance/exit ramp gores, cross walks and street intersections.
- Immediately upstream and downstream of bridges.
- Immediately upstream of cross slope reversals.
- On side streets at intersections.
- At the end of channels in cut sections.
- Behind curbs, shoulders, or sidewalks to drain low areas.
- Where necessary to collect snow melt.

Inlets should not be located in the path where pedestrians are likely to walk.

12.9 Inlet Interception Calculations

12.9.1 Spacing

As discussed above a number of inlets are required to collect runoff at locations with little regard for contributing drainage area. These should be plotted on the plan first. Next, it is best to start locating inlets from the crest and working down grade to the sag points. The process is as follows: the location of the first inlet from the crest can be found by determining the length of pavement and the area back of the curb sloping toward the roadway that generates the design runoff. The design runoff can be computed as the maximum allowable flow in the curbed channel that will not exceed the design criteria. Where the contributing drainage area consists of a strip of land parallel to and including a portion of the highway, the first inlet can be calculated as using Equation 12.7, which is an alternate form of the Rational Equation.

$$L = \frac{43560\ Q_t}{C\ i\ W} \qquad \textbf{(12.7)}$$

Where: L = distance from the crest, ft
Q_t = maximum allowable flow, ft^3/sec
C = composite runoff coefficient for contributing drainage area
W = width of contributing drainage area, ft
i = rainfall intensity for design frequency, in/hr

If the drainage area contributing to the first inlet from the crest is irregular in shape, trial and error will be necessary to match a design flow with the maximum allowable flow.

12.9 Inlet Interception Calculations (continued)

12.9.1 Spacing (continued)

To space successive down grade inlets, it is necessary to compute the amount of flow which will be intercepted by the inlet, Q_i, and subtract it from the total gutter flow to compute the by-pass flow. The by-pass flow from the first inlet is added to the computed flow to the second inlet, the total of which must be less than the maximum allowable flow dictated by the criteria. Table 12-4 is an example of an inlet spacing computation sheet that can be utilized to record the spacing calculations.

Inlets on grade are usually designed for the following percentage capture:

Curb Opening Inlets---- 75%
Slotted Drain & Grate-- 90%

Inlets on grade are rarely designed to capture 100% of the flow; those instances are limited to locations where the consequence of by-pass is undesired; such as the superelevation is reversing or approaching crosswalks. Inlets that pass less than 0.5 cfs should be considered to meet this condition. Inlets that collect off-roadway flows should capture 100% of the flow that would otherwise flow onto the roadway.

12.9.2 Grate Inlets On Grade

The capacity of a grate inlet depends upon its geometry, cross slope, longitudinal slope, total gutter flow, depth of flow and pavement roughness. The depth of water next to the curb is the major factor in the interception capacity of both gutter inlets and curb opening inlets. At low velocities, all of the water flowing in the section of gutter occupied by the grate, called frontal flow, is intercepted by grate inlets and a small portion of the flow along the length of the grate, termed side flow, is intercepted. On steep slopes, a portion of the frontal flow may tend to splash over the end of the grate for some grates. Figure 12-6 can be utilized to determine splash-over velocities for the standard ADOT grate configurations and the portion of frontal flow intercepted by the grate. **Note that the parallel bar grates are the most efficient grates on steep slopes but are not bicycle safe.** Inlet interception capacity has been investigated by the FHWA. The grates tested in an FHWA research study are described in, "Drainage of Highway Pavements," HEC 12.

The ratio of frontal flow to total gutter flow, E_o, for straight cross slope is given by the following equation:

$$\mathbf{E_o = Q_w/Q = 1 - (1 - W/T)^{2.67}} \qquad \mathbf{(12.8)}$$

Where: Q = total gutter flow, ft^3/sec
Q_w = flow in width W, ft^3/sec
W = width of depressed gutter or grate, ft
T = total spread of water in the gutter, ft

12.9 Inlet Interception Calculations (continued)

Figure 12-2 provides a graphical solution of E_o for either straight cross slopes or depressed gutter sections. The ratio of side flow, Q_s, to total gutter flow is:

$$\mathbf{Q_s/Q = 1 - Q_w/Q = 1 - E_o} \qquad \mathbf{(12.9)}$$

The ratio of frontal flow intercepted to total frontal flow, R_f, is expressed by the following equation:

$$\mathbf{R_f = 1 - 0.09(V - V_0)} \qquad \mathbf{(12.10)}$$

Where: V = velocity of flow in the gutter, ft/sec
V_o = gutter velocity where splash-over first occurs, ft/sec

This ratio is equivalent to frontal flow interception efficiency. Figure 12-6 provides a solution of equation 12.10 which takes into account grate length, bar configuration and gutter velocity at which splash-over occurs. The gutter velocity needed to use Figure 12-6 is **total gutter flow** divided by the area of flow.

Figure 12-5 is a nomograph to solve for velocity in a triangular gutter section with known cross slope, slope and spread.

The ratio of side flow intercepted to total side flow, R_s, or side flow interception efficiency, is expressed by:

$$\mathbf{R_s = 1 / [1 + (0.15V^{1.8}/S_xL^{2.3})]} \qquad \mathbf{(12.11)}$$

Where: V = velocity of flow in gutter, ft/sec
L = length of the grate, ft
S_x = cross slope, ft/ft

Figure 12-7 provides a solution to equation 12.11.

The efficiency, E, of a grate is expressed as:

$$\mathbf{E = R_fE_o + R_s(1 - E_o)} \qquad \mathbf{(12.12)}$$

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$\mathbf{Q_i = EQ = Q[R_fE_o + R_s(1 - E_o)]} \qquad \mathbf{(12.13)}$$

12.9 Inlet Interception Calculations (continued)

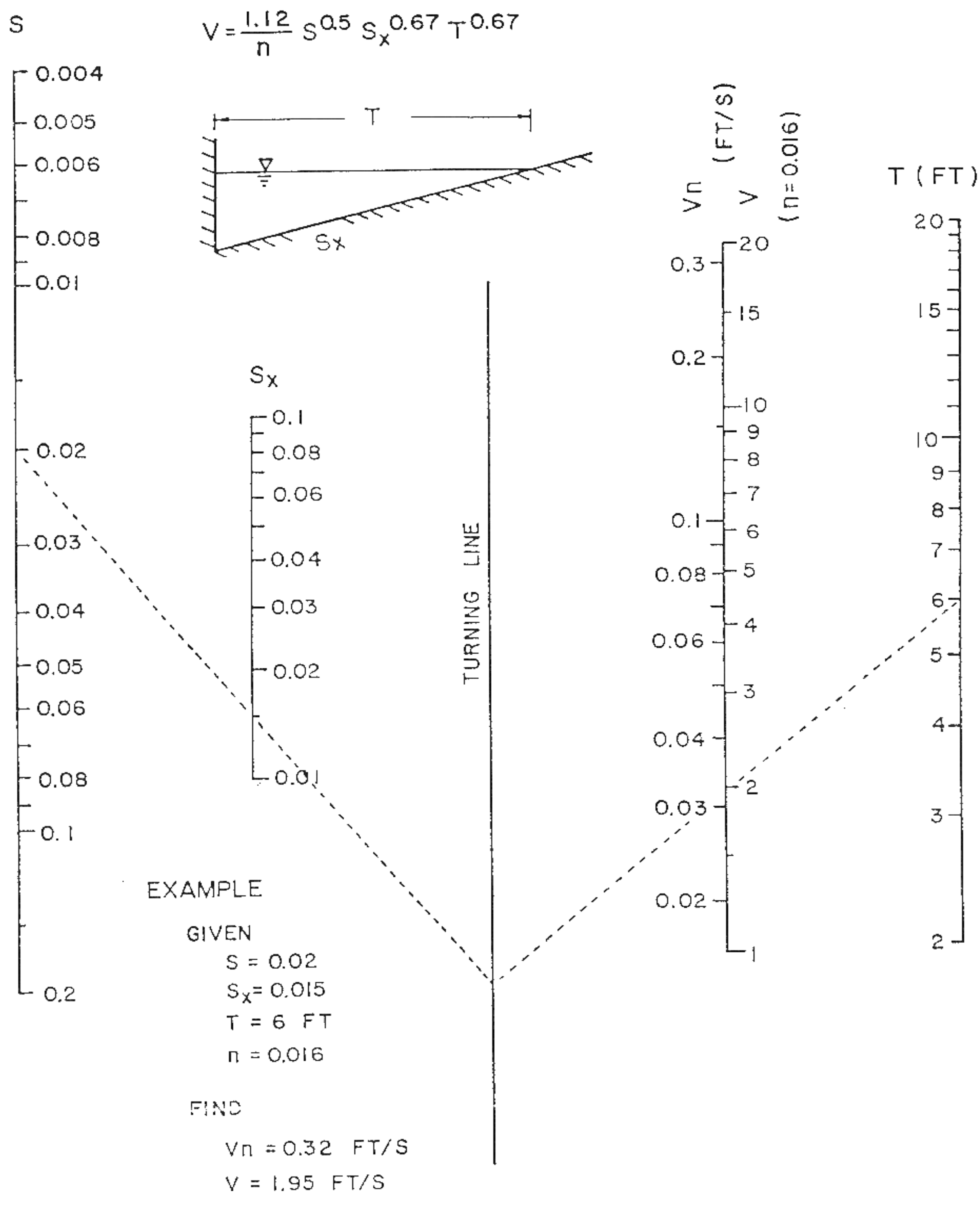


Figure 12-5 Velocity In Triangular Gutter Sections

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

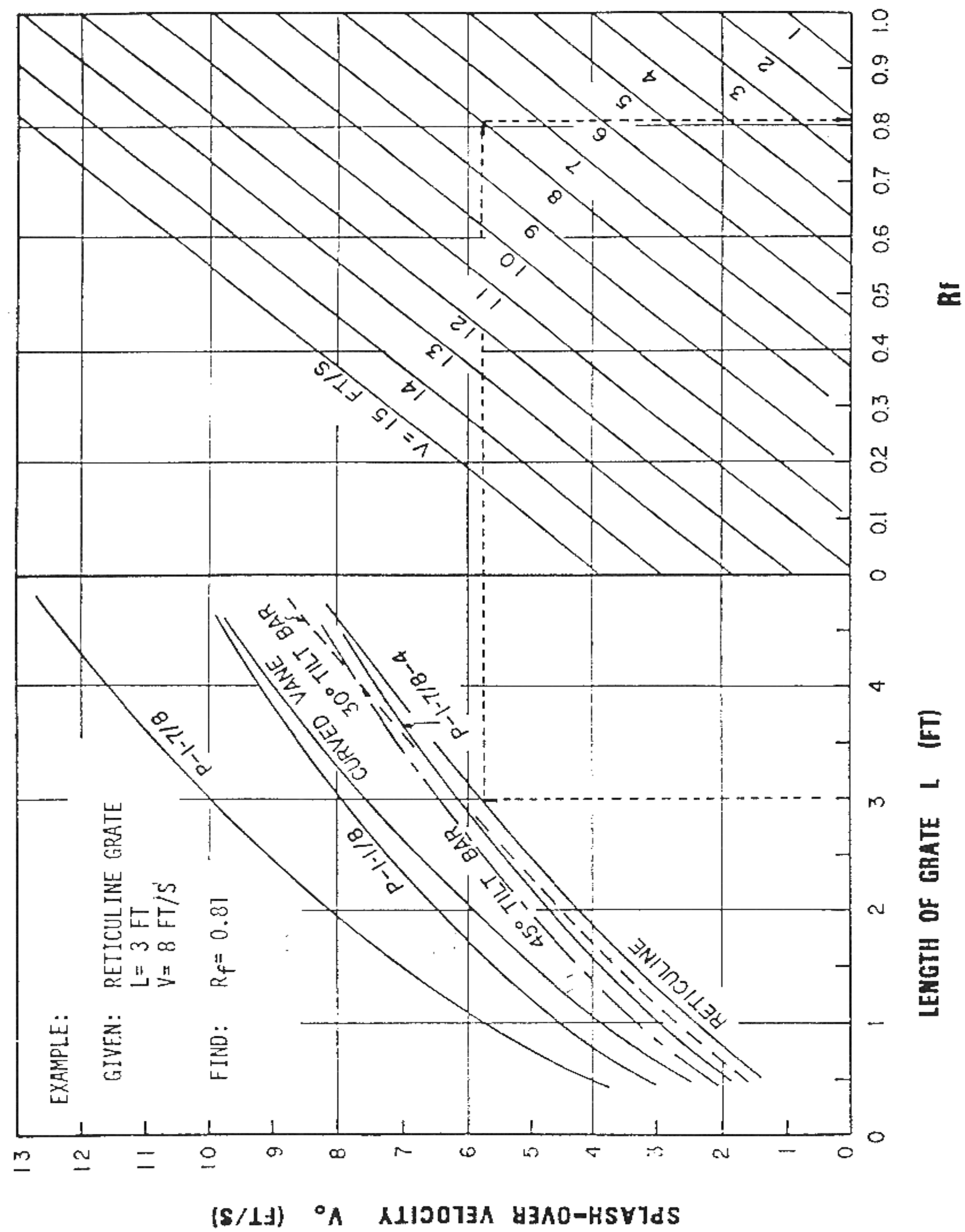


Figure 12-6 Grate Inlet Frontal Flow Interception Efficiency

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

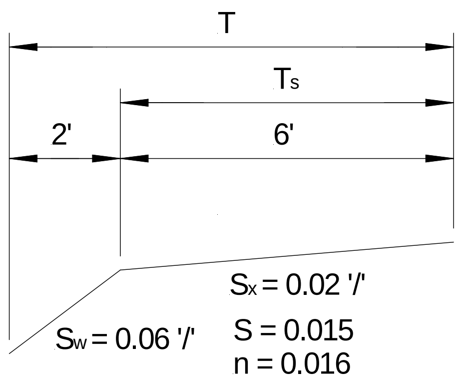
12.9.2 Grate Inlets On Grade (continued)

Example Problem

Given: Roadway in Chandler
Drainage Area: 40 ft landscape strip, C = 0.35, g= 1.5 %
2-12-ft Lanes @ 0.02 ft/ft and 2-ft gutter at 0.06 ft/ft, C=0.95
10-year design,

Allowable spread T = 2+12/2=8.0 ft, n = 0.016
g = 1.5, S_x = 0.02, S_S=0.02, S_w = 0.06

Find: Maximum allowable flow Q_T
Q_i intercepted by ADOT EF-1 grate
Q_r flowby
Location of first and second inlets from crest of hill



Sketch:

Solution:

1. Solve for Q_s using Fig. 12-1
   T_s = 6; Sx = 0.02; Q_s = 0.751 cfs
2. Use Figure 12-2 to find E_o
   S_w/S_x = 0.06/0.02 = 1.5; W/T = 2/8 = 0.25; E_o = 0.64 = Q_w/Q_T
3. Find total Q_T (maximum allowable flow)
   $Q_T = Q_s/(1-E_o)$ = 0.751/(1 - 0.64) = <u>2.09 cfs</u>
4. From Figure 12-5, V = 2.903 ft/s. For and ADOT EF grate, use the reticuline parameters. Splash over velocity is 6.18 ft/sec.
5. From Figure 12-6, R_f = 1.0; From Figure 12-7 R_s = 0.22
6. Using Equation 12.13
   $Q_i = Q_T\,[R_f E_o + R_s\,(1-E_o)]$
   $Q_i = 2.09[(1.0 \times 0.64) + 0.22(1 - 0.64)]$ = <u>1.50 cfs</u>
7. $Q_r = Q_T - Q_i$, Q_r = 2.09-1.50 = <u>0.59 cfs</u>

12.9 Inlet Interception Calculations (continued)

12.9.2 Grate Inlets On Grade (continued)

8. Locate first inlet from crest.

Using equation 12.7, $L = \frac{Q_t(43560)}{CiW}$

Where: L = distance from the crest, ft
Q_t = maximum allowable flow, cfs
C = composite runoff coefficient for contributing drainage area
W = width of contributing drainage area, ft
i = rainfall intensity for design frequency, in/hr

What length of roadway and embankment will generate a Q_t of 2.09 cfs.

To find i, first solve for t_c; For landscape area

C = 0.35 S = 0.5%,

Assume all travel time is in gutter. Gutter flow V = 2.9 ft/sec.

Try 700 ft, $t_c = 700/(2.9 \times 60) = 4.0$ min. Use min t_c = 10 min

For highway in Chandler, at t_c =10 min, i = 4.09 in/hr

Solve for weighted C value: C= [(40 × 0.35) + (26 x 0.95)]/66 = 0.586

L = (2.09)(43560)/(0.586)(4.09)(66) = 575 ft, since this is based on minimum travel time, use this value as max. spacing.

Place first inlet 575 ft from crest.

9. To locate second inlet:
Q_T = 2.09 cfs, $Q_{by\text{-}pass}$ = 1.60 cfs, $Q_{allowable}$ = 2.09-1.60 = 0.49 cfs
Assuming similar drainage area and t_c, i = 4.09 in/hr
L = 0.49(43560)/ (0.568)(4.09)(66) = 139 ft.

Place second inlet no more than 139 ft from first inlet.

12.9 Inlet Interception Calculations (continued)

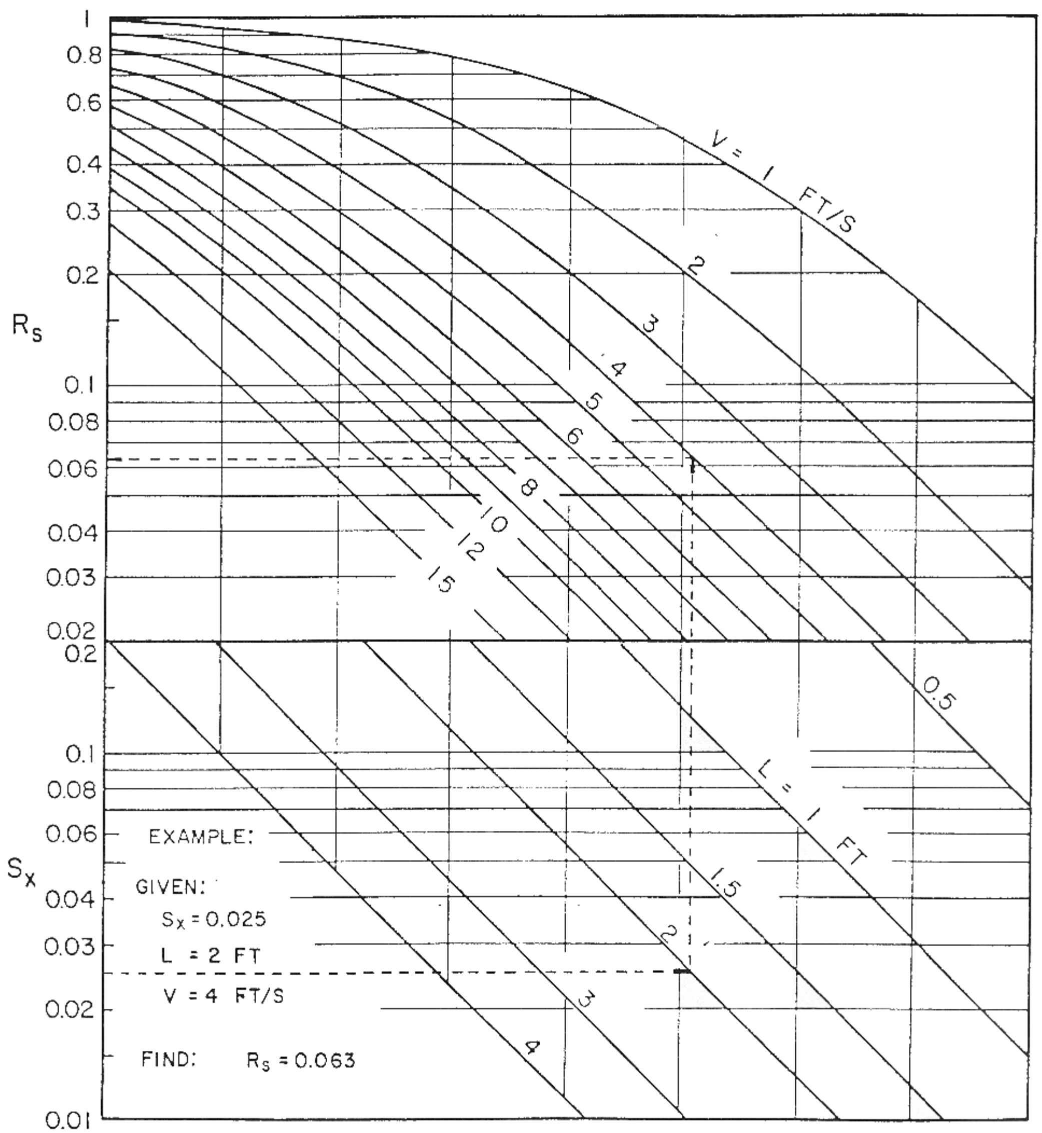


Figure 12-7 Grate Inlet Side Flow Interception Efficiency

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

12.9.3 Grate Inlets In Sag

Although curb-opening inlets are generally more efficient to grate inlets at a sag, grate inlets can be used successfully. For minor sag points where debris potential is limited, grate inlets without a curb opening inlet can be utilized. An example of a minor sag point might be on a ramp as it joins a local street. Curb opening inlets with grates are preferred at sag points where debris is likely such as on a city street. For major sag points such as on divided high speed highways, a combination slotted drain and grate inlet is preferable to a grate inlet because of its hydraulic capacity. When grates are used, it is good practice to assume half the grate is clogged with debris. Where the inlets connect to a pump station, curb opening inlets should not be used.

Where significant ponding can occur, in locations such as underpasses and in sag vertical curves in depressed sections, it is good engineering practice to place a minimum of one flanking inlet on each side of the sag point inlet. The flanking inlets should be placed so they will limit spread on low gradient approaches to the low point and act in relief of the inlet at the low point if it should become clogged or if the allowable spread is exceeded. A further discussion and methodology is given in Section 12.12.8.

A grate inlet in a sag operates as a weir up to a depth of about 0.4 ft and as an orifice for depths greater than 1.4 ft. Between these depths, a transition from weir to orifice flow occurs. The capacity of a grate inlet operating as a weir is:

$$\mathbf{Q_{\mathit{i}}=3Pd^{1.5}} \tag{12.14}$$

Where: 3.0 = weir coefficient
P = perimeter of grate excluding bar widths and side against curb, ft
d = depth of water at along edge of grate, for the sloping side it is measured at the c.g. of flow, ft

The capacity of a grate inlet operating as an orifice is:

$$\mathbf{Q_{\mathit{i}}=0.67A(64.4d)^{0.5}} \tag{12.15}$$

Where: 0.67 = orifice coefficient
A = clear opening area of the grate, ft^2
d = depth of water at along sides of grate, measured form the c.g. of flow, ft
32.2 ft/sec^2 =G

$$\mathbf{Q_{\mathit{i}}=5.38A(d^{0.5})}$$

12.9 Inlet Interception Calculations (continued)

12.9.3 Grate Inlets In Sag (continued)

Figure 12-8 is a plot of equations 12.15 and 12.16 for various grate sizes. The effects of grate size on the depth at which a grate operates as an orifice is apparent from the chart. Transition from weir to orifice flow results in interception capacity less than that computed by either weir or the orifice equation. This capacity can be approximated by drawing in a curve between the lines representing the perimeter and net area of the grate to be used.

Example Problem

The following example illustrates the use of Figure 12-8.

Given: A symmetrical sag vertical curve with equal bypass from inlets upgrade of the low point;
Using ADOT EF-1 grate, consider 50% clogging of the grate. Allowable spread = 8 ft.
What is Q captured.

S_x = 0.02 ft/ft, S_W=0.06 ft/ft w=2.0 ft. $T_{allow.}$ = 8 ft. n = 0.016

Find: Q without local depression.

Depth at gutter line=6(0.02)+2(0.06)=0.12+0.12=0.24ft, 2.88 inches.
Depth at face of grate = 6 (0.02)=0.12 ft., 1.44 inches = 0.12 ft.

Solution:

Center of gravity of flow is based on a depth of

d=1.44{1+[(1.44*0.33+2.88*0.67)/(1.44+2.88)]}/12
d=1.44{1+0.556)/12=2.24/12=0.187 ft., d< 0.4 ft, use weir equation.

$Q= 3(0.5)[2(2.0)(0.187^{1.5})+3.25(0.12^{1.5})]=$
Q= 1.5[0.323+0.135]= 1.5[0.458]
Q= 0.687

The Q captured for 8 ft of spread is 0.687 cfs., if the approach flow is equal in both directions this can have a value of 0.343 cfs.

AASHTO geometric policy recommends a gradient of 0.3% within 50 ft of the level point in a sag vertical curve.
Check T at S = 0.003 for the design approach flow:
Q approach= 0.343cfs, S=0.003, T = 8.2 ft. Figure 12-1

Thus a single EF-1 grate, 50% clogged is adequate to intercept the design flow at a spread that does not exceed design spread, however the spread on the approaches to the low point will exceed design spread. However, the tendency of grate inlets to clog completely warrants consideration of a combination inlet, or curb-opening inlet in a sag where ponding can occur, and flanking inlets on the low gradient approaches.

12.9 Inlet Interception Calculations (continued)

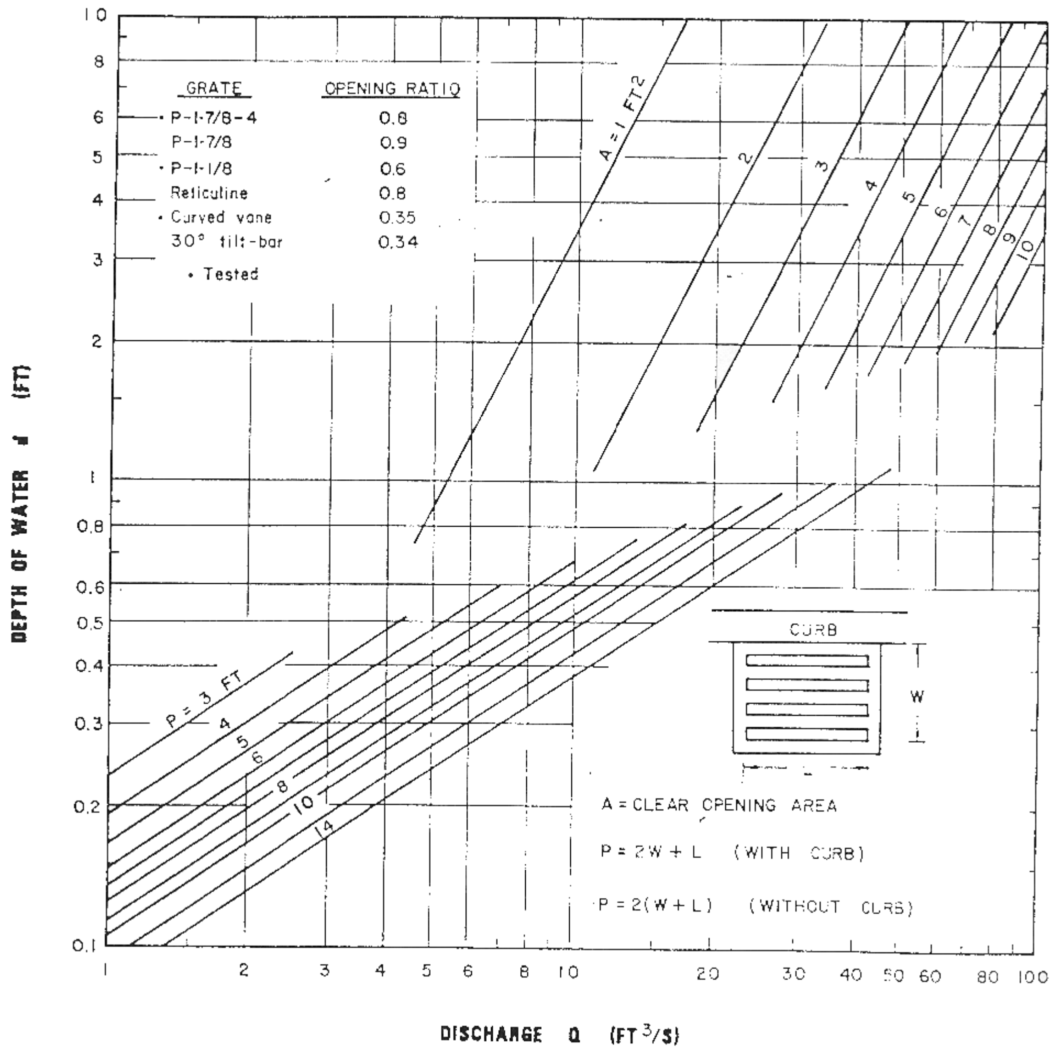


Figure 12-8 Grate Inlet Capacity In Sump Conditions

Source: HEC 12

12.9 Inlet Interception Calculations (continued)

12.9.4 Curb Opening Inlets On Grade

Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging tendencies and offer little interference to traffic operation. However, their lack of filtering of trash makes them undesirable in pump station collection systems. They are a viable alternative to grates in many locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.

The length of curb-opening inlet required for total interception of gutter flow on a pavement section with a straight cross slope is expressed by:

$$\mathbf{L_T = 0.6Q^{0.42}S^{0.3}(1/nS_x)^{0.6}} \qquad \textbf{(12.16)}$$

Where: L_T = curb opening length required to intercept 100% of the gutter flow, ft

The length of inlet required for total interception by depressed curb-opening inlets or curb-openings in depressed gutter sections can be found by the use of an equivalent cross slope, S_e, in equation 12.16.

$$\mathbf{S_e = S_x + S'_wE_o} \qquad \textbf{(12.17)}$$

Where: S'_w = cross slope of the gutter measured from the cross slope of the pavement,
S'_w = (a/12W), ft/ft
a = gutter depression, in
E_0 = ratio of flow in the depressed section to total gutter flow. It is determined by the gutter configuration upstream of the inlet.

The efficiency of curb-opening inlets shorter than the length required for total interception is expressed by:

$$\mathbf{E = 1 - (1 - L/L_T)^{1.8}} \qquad \textbf{(12.18)}$$

Where: L = curb-opening length, ft

Figure 12-9 is a nomograph for the solution of equation 12.17, and Figure 12-10 provides a solution of equation 12.18.

12.9 Inlet Interception Calculations (continued)

12.9.4 Curb Opening Inlets On Grade (continued)

Example Problem

The following example illustrates the use of this procedure.

Given: $S_x = 0.03$ ft/ft S = 0.035 ft/ft n = 0.016 Q = 5 ft^3/s
Find: (1) Q_i for a 11-ft curb-opening inlet, uniform cross slope
(2) Q_i for a 11-ft curb-open inlet with composite cross slope, W=2ft, Sw=Sx+2/24=0.1183
(3) Q_i for a 11-ft curb-open inlet with 2" depression and composite cross slope, a = 2 in, W = 2 ft

Solution:
(1) Q_i for a 11-ft curb-opening inlet, uniform cross slope

For uniform cross-slope, $T=\left\{\frac{(Qn/0.56)}{Sx^{1.67}\,S^{0.5}}\right\}^{0.375}$

$$T=\left(\frac{5(0.016)/0.56)}{(0.030)^{1.67}\,(S0.035)^{0.5}}\right)^{0.375}$$

$$T=\left(\frac{(0.1428)}{(2.8x10^{-3})(1.871x10^{-1})}\right)^{0.375}$$

T= 8.2 ft

$$\mathbf{L_T = 0.6Q^{0.42}S^{0.3}(1/nS_x)^{0.6}} \qquad \textbf{(12.16)}$$

Lt=42.3
$L/L_T = 11/42.3 = 0.26$

$$\mathbf{E = 1 - (1 - L/L_T)^{1.8}} \qquad \textbf{(12.18)}$$

$E= 1-(1-0.26)^{1.8}$
E=0.42
$Q_i = EQ = 0.42 \times 5 = \underline{\underline{2.1\ ft^3/s}}$

Graphical solution
From Figure 12-1, T = 8.1 ft
From Figure 12-9, L_T = 42.3 ft
From Figure 12-10, E = 0.42
$Q_i = EQ = 0.42 \times 5 = \underline{\underline{2.1\ ft^3/s}}$

12.9 Inlet Interception Calculations (continued)

12.9.4 Curb Opening Inlets On Grade (continued)

(2) Q_i for a 11-ft curb-open inlet with composite cross slope, W=2ft, Sw=Sx+2/24=0.1183
See page 23 for spread in a composite section.

Sw/Sx=0.1183/0.03=3.94
Try Q_s = 1.18; then Q_w=5.0-1.18 = 3.82; and Q_w/Q=3.82/5.0 = 0.764;
From Figure 12-2, W/T = 0.30, then T = 2.0/0.30 = 6.67 ft. and T_s = 6.67 – 2.0 = 4.67 ft.
From Fig 12-1, Qn=0.018,Q_s = 0.018/0.016=1.13 ft^3/s OK

From above, Q_w/Q= E_o = 0.764,

$$\mathbf{S_{e=}\ S_{x+}\ S'_w{*}E_0} \quad \textbf{(12.17)}$$

$S_{e=}$ 0.03+0.083*0.764= 0.0934

$$\mathbf{L_T = 0.6Q^{0.42}S^{0.3}(1/nS_e)^{0.6}} \quad \textbf{(12.16)}$$

Lt= 21.4; L/Lt=11.0/21.4=0.51

$$\mathbf{E = 1 - (1 - L/L_T)^{1.8}} \quad \textbf{(12.18)}$$

E= 1-(1-0.51)$^{1.8}$
E=0.73
then Q_i = 0.73 × 5 = <u>3.65 ft^3/s</u>

Graphic Solution:
From Figure 12-9 L_T = 21.4 then L/L_T = 11/21.4 = 0.51

From Figure 12-10 E = 0.73, then Q_i = 0.73 × 5 = <u>3.65 ft^3/s</u>

(3) Q_i for a 11-ft curb-open inlet with 2” depression and composite cross slope, a = 2 in, W = 2 ft
The approach spread is the same as for example 2, T=6.7 ft. At the inlet the water will redistribute, so must redo the spread computation for determination of Lt.

At inlet Sw=0.1133+0.0833=0.1966; Sw/Sx=0.1966/0.03=6.55
Try Q_s = 0.29; then Q_w=5.0-0.29 = 4.71; and Q_w/Q=4.71/5.0 = 0.942;
From Figure 12-2, W/T = 0.41, then T = 2.0/0.41 = 4.88 ft. and T_s = 4.88 – 2.0 = 2.88 ft.
From Fig 12-1, Qn=0.0048,Q_s = 0.0048/0.016=0.3 ft^3/s OK

From above, Q_w/Q= E_o = 0.942,

$$\mathbf{S_{e=}\ S_{x+}\ S'_w{*}E_0} \quad \textbf{(12.17)}$$

$S_{e=}$ 0.03+0.1133*0.942= 0.1367

$$\mathbf{L_T = 0.6Q^{0.42}S^{0.3}(1/nS_e)^{0.6}} \quad \textbf{(12.16)}$$

Lt= 17.0; L/Lt=11.0/17.0=0.64

12.9 Inlet Interception Calculations (continued)

12.9.4 Curb Opening Inlets On Grade (continued)

$$\mathbf{E = 1 - (1 - L/L_T)^{1.8}} \quad \textbf{(12.18)}$$

$E= 1-(1-0.64)^{1.8}$
$E=0.84$
then $Q_i = 0.84 \times 5 = \underline{\underline{4.2\ ft^3/s}}$

$Qn = 5 \times 0.016 = 0.08\ ft^3/s$
$S_w/S_x = (0.03 + 0.0833+0.0833)/0.03 =6.55$
From Figure 12-3, T/W = 2.6 and T = 5.2 ft
Then W/T (Depress) = 2/5.2 = 0.385
From Figure 12-2, $E_o = 0.91$
$S_e = S_x + S'_wE_0 = 0.03 + 0.1666(0.91) = 0.182$

Graphic Solution:
From Figure 12-9 $L_T = 17.0$ then $L/L_T = 11/17 = 0.64$

From Figure 12-10 E = 0.84, then $Q_i = 0.84 \times 5 = \underline{\underline{4.2\ ft^3/s}}$

12.9.5 Curb Opening Inlets In Sag

The capacity of a curb-opening inlet in sag depends on water depth at the curb, the curb opening length and the height of the curb opening. The inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The equation for the interception capacity of a depressed curb-opening inlet operating as a weir is:

$$\mathbf{Q_i= 2.3\ (L + 1.8\ W)\ d^{1.5}} \quad \textbf{(12.19)}$$

Where: 2.3 = curb-opening coefficient
L = length of curb opening, ft
W = width of depression, ft
D = depth of water at curb measured from the normal cross slope gutter flow line, ft

See Figure 12-11 for a definition sketch.

The weir equation for curb-opening inlets without depression becomes:

$$\mathbf{Qi= 2.3\ Ld^{1.5}} \quad \textbf{(12.20)}$$

The depth limitation for operation as a weir becomes: $d \leq h$

12.9 Inlet Interception Calculations (continued)

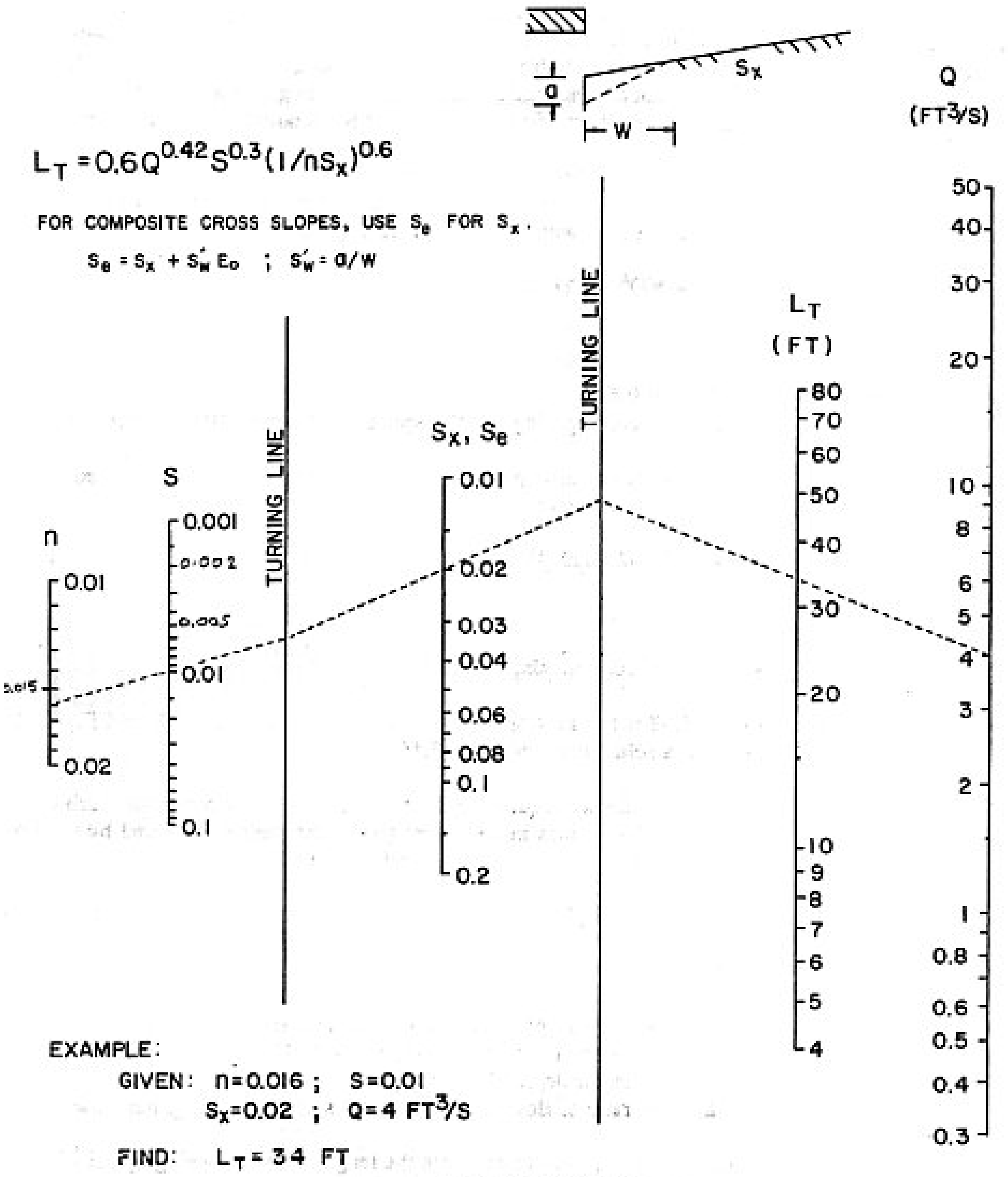


Figure 12-9 Curb-Opening And Longitudinal Slotted Drain

Inlet Length For Total Interception

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

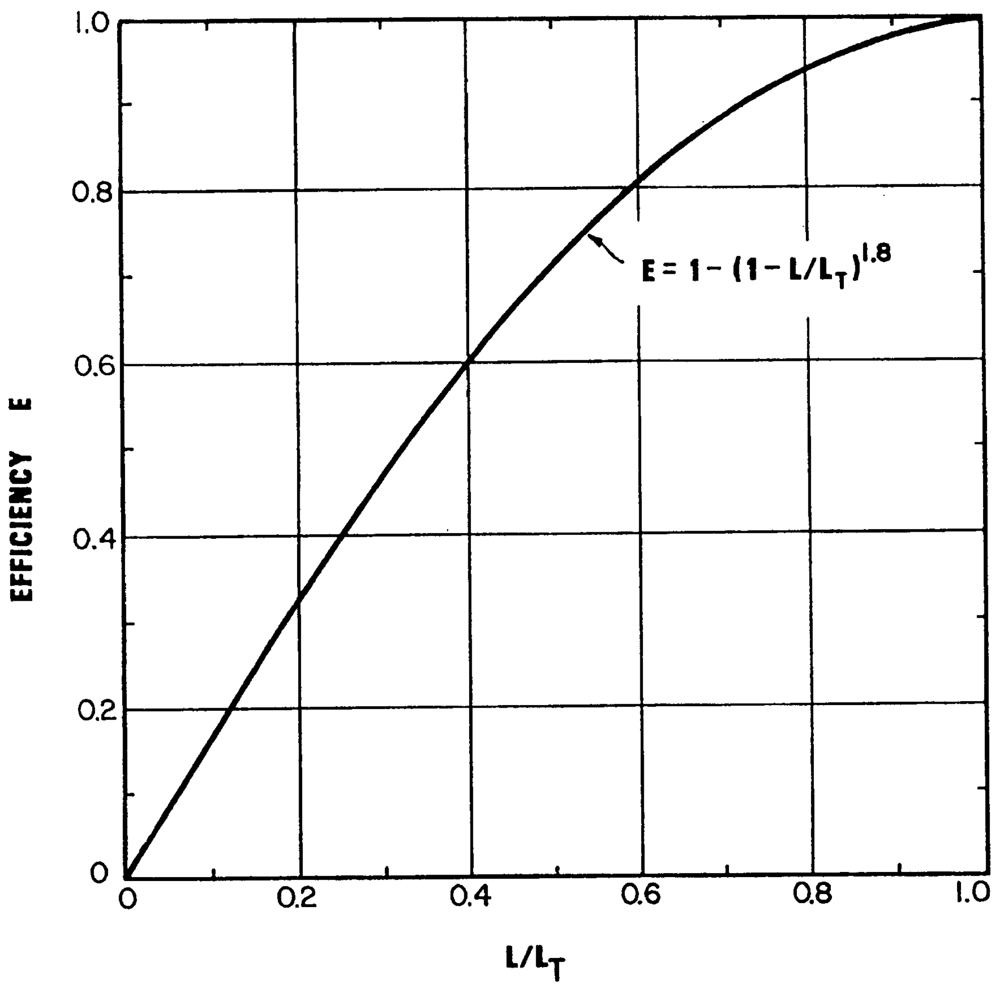


Figure 12-10 Curb-Opening And Slotted Drain Inlet Interception Efficiency

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

12.9.5 Curb Opening Inlets In Sag (continued)

Curb-opening inlets operate as orifices at depths greater than approximately 1.4 × height of curb-opening. The interception capacity can be computed by:

$$\mathbf{Q_i = 0.67\ A[2g(d_i - h/2)]^{0.5}} \qquad \mathbf{(12.21)}$$

Where: 0.67 = orifice coefficient
H = height of curb-opening orifice, ft
A = clear area of opening, ft^2
d_i = depth at lip of curb opening, ft

Note: Equation 12.21 is applicable to depressed and undepressed curb-opening inlets and the depth at the inlet includes any gutter depression.

Example Problem:

Given: Curb-opening inlet in a sump location
L = 7.0 ft h = 5 inches

(1) Undepressed curb opening
S_x = 0.03 T = 8 ft

(2) Depressed curb opening
S_x = 0.03 W = 2.0 ft
a = 2 inches T = 8 ft.

Find: Q_i

Solution:

(1) $d = TS_s = 8 \times 0.03 = 0.24$ ft (2.88 inches) $d < h$ therefore weir controls
$Q_i = C_W\ L\ d^{1.5} = 3.0 \times 7 \times 0.24^{1.5} = 2.9\ ft^3/s$

(2) d = 8(0.03)+2/24=0.24+0.083=0.323 ft (4.88 in.) < (1.4 h) = (1.4*7/12)=0.6 ft, therefore weir controls.

$$\mathbf{Q_i = 2.3\ (L + 1.8\ W)\ d^{1.5}} \qquad \mathbf{(12.19)}$$

P = L + 1.8W = 7+ 1.8(2) = 10.6 ft

$Q_i = 3.0 \times 10.6 \times 0.323^{1.5} = 5.83\ ft^3/s$ (Figure 12-11)

At d = 0.323 ft, the depressed curb-opening inlet has about 100% more capacity than an inlet without depression. In practice, the flow rate would be known and the depth at the curb would be unknown.

12.9 Inlet Interception Calculations (continued)

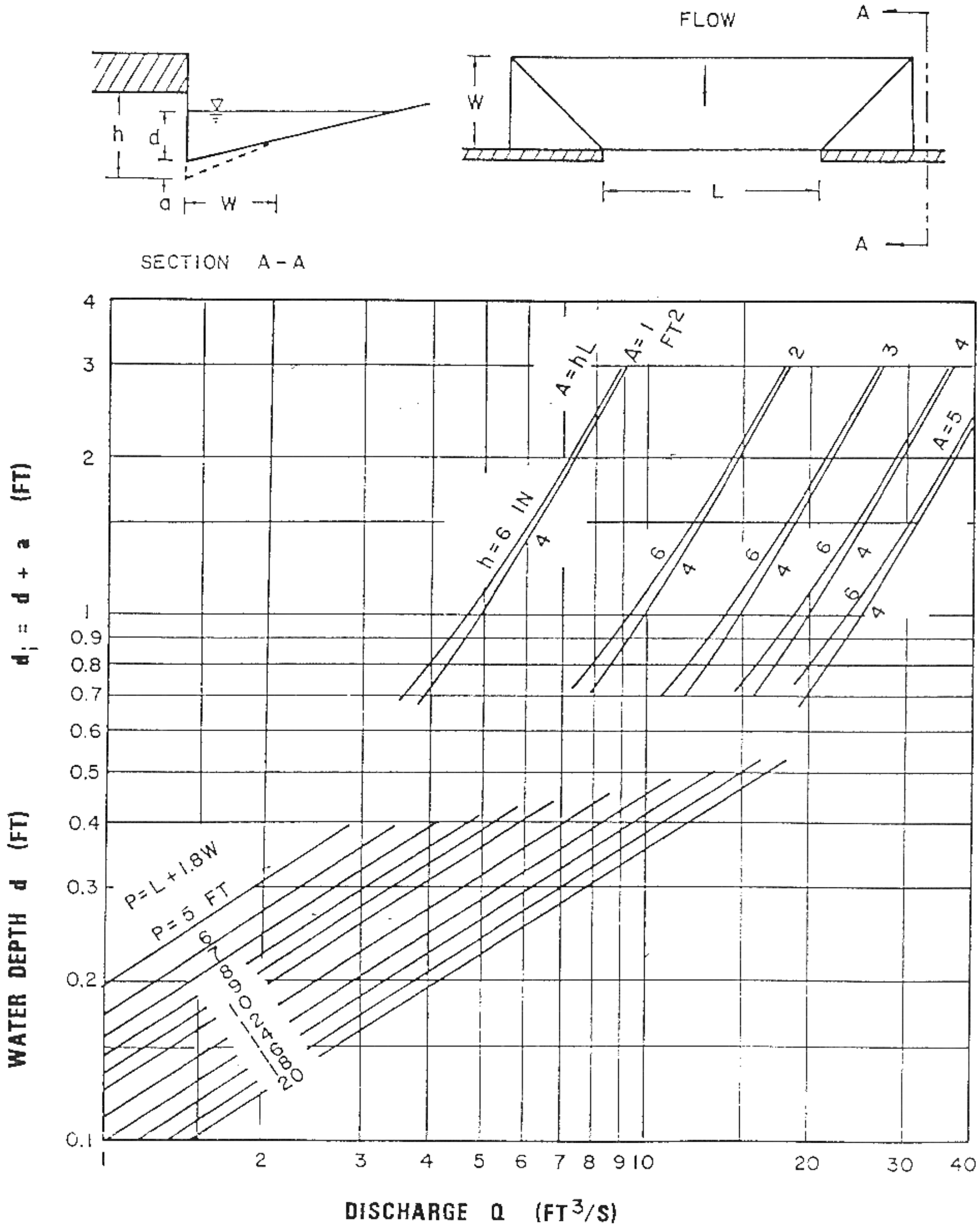


Figure 12-11 Depressed Curb-Opening Inlet Capacity In Sump Locations

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

12.9.6 Slotted Inlets On Grade

Slotted inlets are effective pavement drainage inlets that have a variety of applications. They can be used on curbed or uncurbed sections and offer little interference to traffic operations. They can be placed longitudinally in the gutter or transversely to the gutter. Slotted inlets shall be connected to a clean-out structure, typically a standard catch basin, so they will be accessible to maintenance forces.

12.9.6.1 Longitudinal Placement

Flow interception by slotted inlets and curb-opening inlets is similar in that each is a side weir and the flow is subjected to lateral acceleration due to the cross slope of the pavement. Slotted inlets may have economic advantages in some cases and could be very useful on widening and safety projects where right of way is narrow and existing inlet capacity must be supplemented. In some cases, curbs can be eliminated as a result of utilizing slotted inlets.

The length of a slotted inlet required for total interception of gutter flow on a pavement section with a straight cross slope is expressed by:

$$Lt=0.6Q^{0.42}S^{0.3}(1/nS_x)^{0.6} \tag{12.22}$$

Where: L_T = slotted inlet length required to intercept 100% of the gutter flow, ft

The slot width must be at least 1.75 in for equation 12.23 to be valid.

The efficiency of slotted inlets shorter than the length required for total interception is expressed by:

$$E=1-(1-L/L_t)^{1.8} \tag{12.23}$$

Where: L = slotted inlet length, ft

Figure 12-9 is a nomograph for the solution of equation 12.23, and Figure 12-10 provides a solution of equation 12.24.

The length of inlet required for total interception by a slotted inlet in a composite section can be found by the use of an equivalent cross slope, S_e, in equation 12.23.

$$S_e = S_x + S'_w E_o \tag{12.17}$$

Where: S_x = pavement cross slope, ft/ft
S_w = gutter cross slope, ft/ft
$S'_w = S_w - S_x$
E_0 = ratio of flow in the depressed gutter to total gutter flow, Q_w/Q (See Figure 12-2)

Note that the same equations are used for both slotted inlets and curb opening inlets.

12.9 Inlet Interception Calculations (continued)

12.9.6 Slotted Inlets On Grade (continued)

Example Problem

Given: Longitudinal placement of slotted inlet adjacent to curb.
g = 1% Allowable spread = 10 ft n = 0.016
(1) Uniform cross slope, $S_x = 0.02$
(2) Composite cross slope, $S_x = 0.02$, $S_w = 0.06$, W=2.0
(3) Increase g to 3% and solve for (1) and (2)

Find: (1) Maximum allowable Q
Q_i for a 10 feet slotted inlet on straight cross slope.
(2) Maximum allowable Q
Q_i for a 10 feet slotted inlet on composite cross slope.
(3) Same as above with profile grade increased to 3%.

Solution:

(1) For T = 10 ft, Max Q = 2.394 cfs from Figure 12-1
L_T = 27.2 ft from Figure 12-9 $L/L_T = 10/27.2 = 0.368$
E = 0.56 from Figure 12-10; $Q_i = EQ = 0.56 \times 2.394$ = <u>1.35 cfs intercepted</u>

(2) Q_s = 1.321 cfs from Figure 12-1; W/T = 2.0/10.0= 0.2
$S_w/S_x = 0.06/0.02 = 3$; E_o = 0.53 from Figure 12-2
Max $Q = Q_s/(1 - E_o) = 1.321/(1 - 0.53)$ = <u>2.81 cfs</u>
$S'_w = S_w - S_x = 0.06 - 0.02 = 0.04$
$S_e = S_x + S'_w E_o = 0.02 + (0.04 \times 0.52) = 0.041$
L_T = 18.9 ft from Figure 12-9 $L/L_T = 10/18.9 = 0.53$ E = 0.74 from
Figure 12-10; then $Q_i = EQ = 0.74 \times 2.81$ = <u>2.08 cfs intercepted</u>

The slotted inlet in the composite gutter section will intercept 1.55 times the flow intercepted by the slotted inlet in the uniform section.

(3) From a similar analysis for g = 3%
Uniform Section: Max Q = 4.15 cfs and Q_i = 1.43 cfs
Composite Section: Max Q = 4.92 cfs and Q_i = 2.35 cfs

12.9 Inlet Interception Calculations (continued)

12.9.7 Slotted Inlets In Sag

The use of slotted drain inlets in sag configurations is generally discouraged because of the propensity of such inlets to intercept debris in sags. However, there may be locations where it is desirable to supplement an existing low point inlet with the use of a slotted drain. Slotted inlets in sag locations perform as weirs to depths of about 2.5 inches, dependent on slot width and length. At depths greater than about 5 inches, they perform as orifices. Between these depths, flow is in a transition stage. The interception capacity of a slotted inlet operating as an orifice can be computed by the following equation:

$$Q_i = 0.8LW(2gd)^{0.5} \tag{12.24}$$

Where: W = width of slot, ft
L = length of slot, ft
d = depth of water at slot, ft
g = 32.2 ft/sec^2

For a slot width of 1.75 inches, the above equation becomes:

$$Q_i = 0.94Ld^{0.5} \tag{12.25}$$

The interception capacity of slotted inlets at depths between 0.2 ft and 0.4 ft can be computed by use of the orifice equation. The orifice coefficient varies with depth, slot width, and the length of slotted inlet. Figure 12-12 provides solutions for weir flow and a plot representing data at depths between weir and orifice flow.

12.9.8 Flanking Inlets

At major sag points where significant ponding may occur, such as underpasses or sag vertical curves in depressed sections, it is recommended practice to place a minimum of one flanking inlet on each side of the inlet at the sag point. The flanking inlets should be placed to act in relief of the sag inlet if it should become clogged. Table 12-3 shows the spacing required for various depths at curb criteria and vertical curve lengths defined by K = L/A, where L is the length of the vertical curve in meters and A is the algebraic difference in approach grades. The AASHTO policy on geometrics specifies maximum K values for various design speeds and a maximum K of 51 considering drainage.

Example Problem

Given: K = 130 ft/%, S_x = 0.04, allowable spread is 10 ft

Find: Location of flanking inlets that will function in relief of the inlet at the low point when the inlet at the low point is clogged.

d at sag = 0.4 ft., d at flanking inlet = 0.275 ft.

12.9 Inlet Interception Calculations (continued)

12.9.8 Flanking Inlets (continued)

Solution:

(1) Depth over flanking inlet to carry one-half of the design flow equals 0.63(0.4 ft) = 0.275 ft

(2) Depth from bottom of sag to flanking inlet - 0.4 ft - .275 ft = 0.125 ft

(3) Spacing of flanking inlet =58 ft (from Table 12-3, using d = 0.125 ft).
d= depth at curb line.

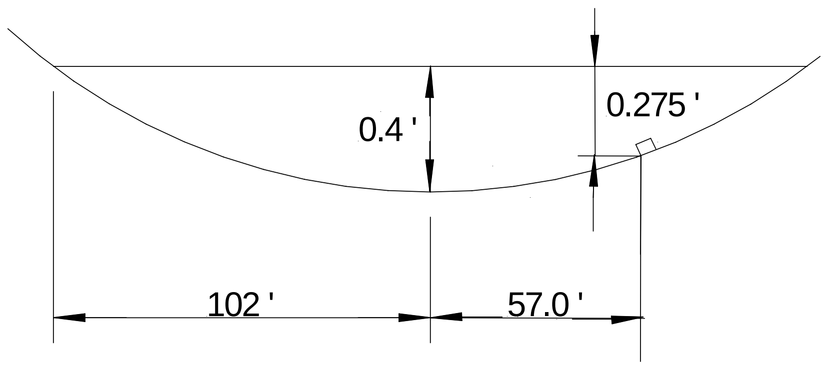


Table 12-3 Flanking Inlet Locations

Distance to flanking inlet in sag vertical curve locations using depth at curb criteria (ft).												
d↓ K→	20	30	40	50	70	90	110	130	160	165	180	220
0.1	20	24	28	32	37	42	47	51	57	57	60	66
0.2	28	35	40	45	53	60	66	72	80	81	85	94
0.3	35	42	49	55	65	73	81	88	98	99	104	115
0.4	40	49	57	63	75	85	84	102	113	115	120	133
0.5	45	55	63	69	84	95	105	114	126	128	134	148
0.5	49	60	69	77	92	104	115	12	139	141	147	162
0.7	53	65	75	84	99	112	12	135	150	152	159	175
0.8	57	69	80	89	106	120	133	144	160	162	170	188
NOTES:1. $\times = (200dK)^{0.5}$, where × = distance from the low point (ft) 2. Drainage maximum K = 165 ft/%. 3. d = depth at curb (ft).												

12.9 Inlet Interception Calculations (continued)

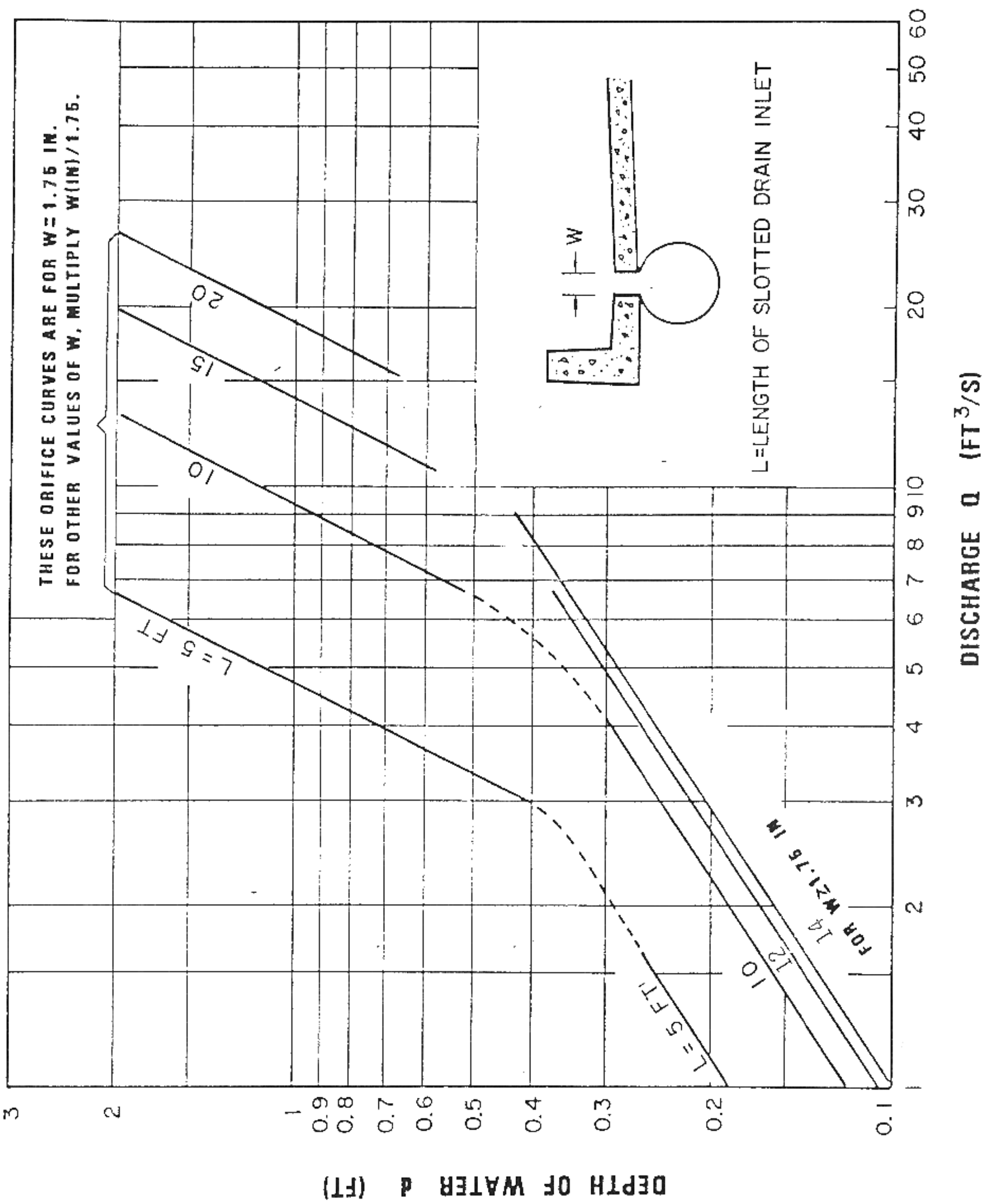


Figure 12-12 Slotted Drain Inlet Capacity In Sump Locations

Source: HEC-12

12.9 Inlet Interception Calculations (continued)

12.9.9 Inlet Spacing Computations

In order to design the location of the inlets for a given project, information such as a layout or plan sheet suitable for outlining drainage areas, road profiles, typical cross sections, grading cross sections, superelevation diagrams and contour maps are necessary. The inlet computation sheet, Table 12-4 (page 12-59), should be used to document the computations. A step-by-step procedure is as follows:

Step 1 Complete the blanks on top of the sheet to identify the job by route, location, date and your initials.

Step 2 Mark on the plan the location of inlets that are necessary even without considering any specific drainage area. See Section 12.11.3 Inlet Locations for additional information.
Step 3 Start at one end of the job, at one high point and work towards the low point, then space from the other high point back to the same low point.

Step 4 Select a trial drainage area approximately 300 to 500 ft below the high point and outline the area including any area that may come over the curb. (Use drainage area maps.) Where practical, large areas of behind the curb drainage should be intercepted before it reaches the highway. (See 12.7.5)

Step 5 Col 1 Describe the location of the proposed inlet by number and station in Col 1 & 2. Identify the curb and gutter type in the Remarks Column 19. A sketch of the cross section should be provided in the open area of the computation sheet.

Step 6 Col 3 Compute the drainage area in hectares and enter in Col 3.

Step 7 Col 4 Select a C value or compute a weighted value based on area and cover type as described in Section 12.6.2.1 and enter in Col 4.

Step 8 Col 5 Compute a time of concentration for the first inlet. This will be the travel time from the hydraulically most remote point in the drainage area to the inlet. See additional discussion in Section 12.6.2.3. The minimum time of concentration should be 10min. Enter value in Col 5.

Step 9 Col 6 Using the Intensity-Duration-Frequency curves, select a rainfall intensity at the t_c for the design frequency. Enter in Col. 6.

Step 10 Col 7 Calculate Q by multiplying Col 3 × Col 4 × Col 6. Enter in Col 7.

Step 11 Col 8 Determine the gutter slope at the inlet from the profile grade — check effect of superelevation. Enter in Col. 8.

Step 12 Col 9 Enter cross slope adjacent to inlet in Col 9 and gutter width in Col 13. Sketch composite cross slope with dimensions.

Step 13 Col 11 For the first inlet in a series (high point to low point) enter Col. 7 in Col. 11 since no previous flowby has occurred yet.

12.9 Inlet Interception Calculations (continued)

12.9.9 Inlet Spacing Computations (continued)

Step 14 Col 12 Using Figure 12-1 or the available computer model, determine the spread T and enter in Col 14 and calculate the depth d at the curb by multiplying T times the cross slope(s) and enter in Col 12. Compare with the allowable spread as determined by the design criteria in Section 12.9. If Col. 15 is less than the curb height and Col. 14 is near the allowable spread, continue on to step 16. If not OK, expand or decrease the drainage area to meet the criteria and repeat steps 5 through 14. Continue these repetitions until column 14 is near the allowable spread then proceed to step 15.

Step 15 Col 15 Calculate W/T and enter in Col 15.

Step 16 Col 16 Select the inlet type and dimensions and enter in Col 16.

Step 17 Col 17 Calculate the Q intercepted (Q_i) by the inlet and enter in Col 17. Utilize Fig. 12-1 and 12-2 or 12-3 to define the flow in the gutter. Utilize Fig. 12-2, 12-6 and 12-7 and equation 12.13 to calculate Q_i for a grate inlet and Fig. 12-9 and 12-10 to calculate Q_i for a curb-opening inlet. See Section 12.12.2 for a grate inlet example and Section 12.12.4 for a curb-opening inlet example.

Step 18 Col 18 Calculate the flowby by subtracting Col 17 from Col 11 and enter into Col 18 and also into Col. 10 on the next line if an additional inlet exists downstream.

Step 19 Col 1-4 Proceed to the next inlet down grade. Select an area approximately 270 to 300 feet below the first inlet as a first trial. Repeat steps 5 through 7 considering only the area between the inlets.

Step 20 Col 5 Compute a time of concentration for the second inlet downgrade based on the area between the two inlets.
Step 21 Col 6 Determine the intensity based on the time of concentration determined in step 19 and enter it in Col 6.

Step 22 Col 7 Determine the discharge from this area by multiplying Col 3 × Col 4 × Col 6. Enter the discharge in Col 7.

Step 23 Col 11 Determine total gutter flow by adding Col 7 and Col 10 and enter in Col 11. Column 10 is the same as Column 18 from the previous line.

Step 24 Col 12 Determine "T" based on total gutter flow (Col. 11) by using figure 12-1 or 12-3 and enter in Col. 14, (If "T" in Col. 14 exceeds the allowable spread, reduce the area and repeat steps 19-24. If "T" in Col. 14 is substantially less than the allowable spread, increase the area and repeat steps 19-24.)

Step 25 Col 16 Select inlet type and dimensions and enter in Col. 16.

Step 26 Col 17 Determine Q_i and enter in Col 17 — See instruction in step 17.

12.9 Inlet Interception Calculations (continued)

12.9.9 Inlet Spacing Computations (continued)

Step 27 Col 18 Calculate the flowby by subtracting Col 17 from Col 7 and enter in Col 16. This completes the spacing design for this inlet.

Step 28 Go back to step 19 and repeat step 19 through step 27 for each subsequent inlet. If the drainage area and weighted "C" values are similar between each inlet, the values from the previous grate location can be reused. If they are significantly different, recomputation will be required.

12.9 Inlet Interception Calculations (continued)

Storm Drainage Systems ROUTE_________ Location________________________ DATE_______________
ADOT Drainage Manual COMPUTED BY_________________________________ SHEET_____OF_____
INLET COMPUTATION SHEET

INLET		GUTTER DISCHARGE Design Frequency ______					GUTTER DISCHARGE Allowable Spread ______								INLET DISCHARGE			REMARKS
ID. NUMBER	STATION.	DRAIN .AREA "A" (Acres)	RUNOFF COEF "C"	TIME OF CONC. "T_C" (min)	Rain Intensity "I" (in/h)	Q= CIA (cfs)	GRADE, G (%)	CROSS SLOPE S_x (ft/ft)	PREV. RUNBY (cfs)	TOTAL GUTTER FLOW (cfs)	DEPTH "d" (ft)	GUTTER WIDTH "W" (ft)	SPREAD "T" (ft)	W/T	INLET TYPE	INTERCEPT "Q_i" (cfs)	RUNBY "Q_r" (cfs)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Table 12-4 Inlet Spacing Computation Sheet

A minimum velocity of 3 ft/s is desirable in the storm drain in order to prevent sedimentation from occurring in the pipe.